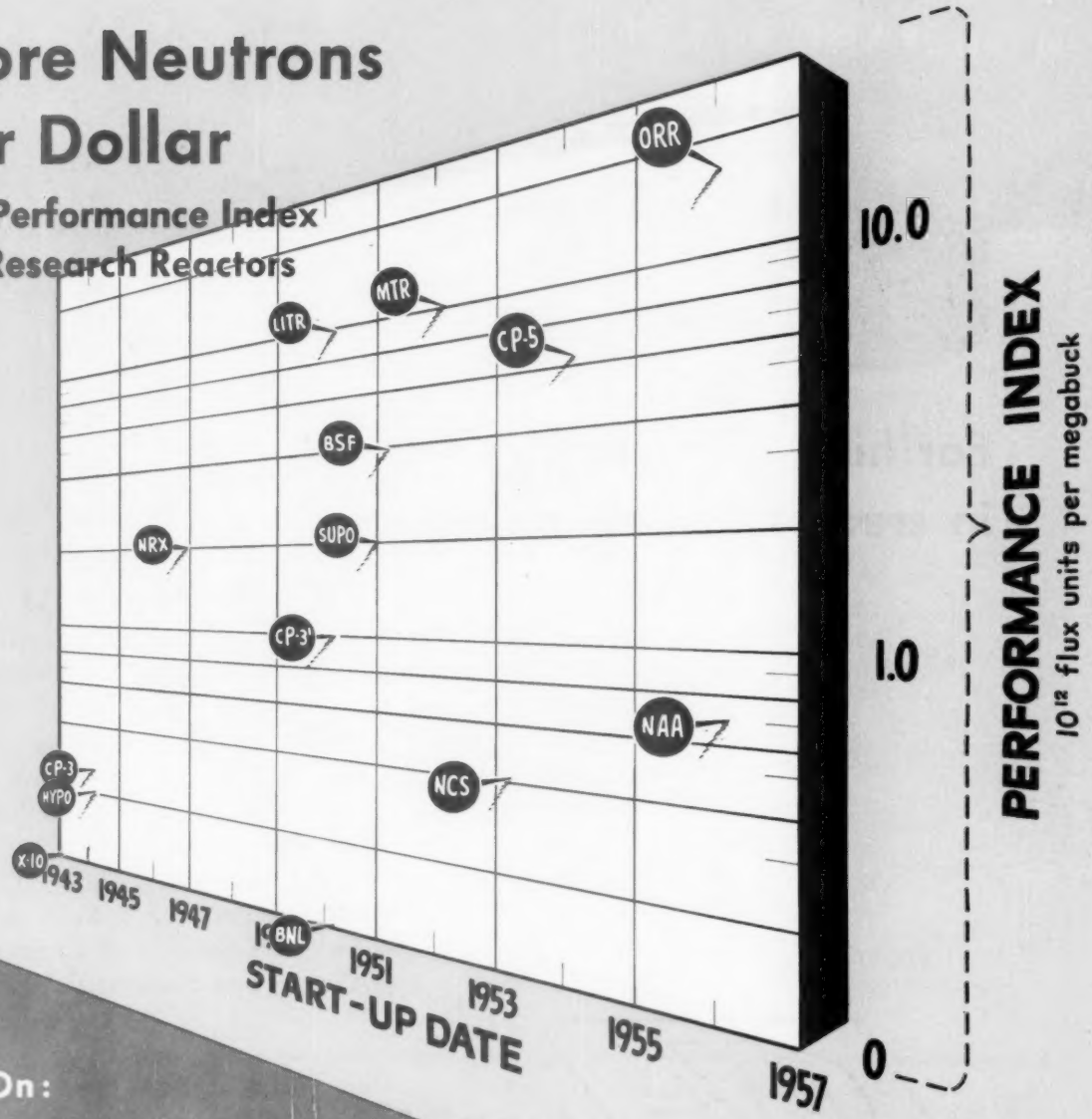
April 1954

NUCLEONICS

A McGRAW-HILL PUBLICATION ★ SEVENTY-FIVE CENTS

More Neutrons Per Dollar

—A Performance Index For Research Reactors



Special Report On:

RESEARCH REACTORS—

What you need to know to build one

See page 7

You can easily remove the jet assembly in a MCF pump for cleaning.

For high efficiency in creating ***high vacuum***

CVC's type MCF fractionating oil diffusion pumps are designed particularly for high efficiency in pumping large gas loads or gases of low molecular weight.

This series of high vacuum pumps ranges from a 2-inch diameter model for exhausting cathode ray tubes to models several feet in diameter for giant synchro-cyclotrons and linear accelerators. Ultimate vacuum is 5 x 10^{-7}mm Hg at 25° C without cold baffles or traps.

A new data sheet describes the MCF series in detail. We would like to send you a copy, or to discuss any problem you have that might involve the creation, measurement, or use of high vacuum. Write *Consolidated Vacuum Corporation, Rochester 3, N. Y.* (a subsidiary of Consolidated Engineering Corporation, Pasadena, California).

CVC

Consolidated Vacuum Corporation

Rochester 3, N. Y.

formerly DPi Vacuum Equipment Dept.

designers and manufacturers of high vacuum equipment

SALES OFFICES: PALO ALTO, CALIF. • CHICAGO, ILL. • CAMDEN, N. J. • NEW YORK, N. Y. • BOSTON, MASS.

NUCLEONICS

APRIL • 1954

Vol. 12, No. 4

RESEARCH REACTORS: What You Need to Know to Build One... 7
A NUCLEONICS Special Report

Fast-Neutron Dosimetry in a Small Tissue-Equivalent Phantom... 17
W. A MILLS and G. S. HURST

The Materials Testing Reactor... 20
JOHN R. HUFFMAN

Gamma-Ray Backscattering... 27
GERALD J. HINE and RICHARD C. McCALL

The Biological Effectiveness of Thermal Neutrons on Mice—II... 31
JAMES T. BRENNAN, PAYNE S. HARRIS, ROBERT EMERSON CARTER, and WRIGHT H. LANGHAM

Using a Reactor Simulator for Design Analysis... 36
R. B. SPOONER

How to Use Gas Evolution for Dosimetry of High Gamma, Neutron Fluxes... 40
EDWIN J. HART and SHEFFIELD GORDON

Reliable Scaling Circuits for Decade Tubes... 44
J. C. BAKER and G. G. EICHHOLZ

Optimizing Multiplication Factors of Heterogeneous Reactors... 50
IVAN C. ATKINSON and RAYMOND L. MURRAY

Problems in Using High-Voltage Electrons for Sterilization... 54
W. D. BELLAMY and E. J. LAWTON

Cross Sections

Using Autoradiography for Quantitative Study of U in Ore... 58
A. S. BHATNAGAR and P. C. GHOSH

A Biosynthesis of C^{14}-Labelled Glycogen... 59
C. C. HASSETT, W. H. SUMMERSON, and F. SOLOMON

Device for Loading Cobalt-60 Cartridges in Tubing for Cancer Therapy... 62
GEORGE W. CALLENDINE, Jr. and JOSEPH L. MORTON

Activation of Nuclear Isomers by Gamma Rays... 64
GARMAN HARBOTTLE

Nuclear Engineering

Thermodynamic Properties of Liquid Sodium... 74
JOHN F. LEE

Departments

BOOKS..... 68 NEWS..... 78 PRODUCTS AND MATERIALS.... 84

JEROME D. LUNTZ, Editor
C. J. MOSBACHER, JR., Managing Editor
James J. Dutton, Associate Editor
Thomas L. Cramer, Assistant Editor
Nancy Purves Case, Editorial Assistant
Dorothy Pappachristou, Editorial Assistant
Harry Phillips, Art Director
George B. Bryant, Jr., Washington Office
Jesse Mock, Washington Office
Joseph Van Denburg, Jr., World News

KEITH HENNEY, Consulting Editor

ABC ABP

H. W. MATEER, Publisher
WALLACE B. BLOOD, Manager
R. S. Quint, Buyers Guide Manager
D. H. Miller, J. Girdwood, New York
Wm. S. Hodgkinson, New England
Warren W. Shew, Philadelphia
C. D. Wardner, James T. Hauptli, Chicago
J. L. Phillips, Cleveland
T. H. Carmody, R. C. Alcorn, San Francisco
Carl W. Dysinger, Los Angeles
Robert H. Sidur, Atlanta
J. E. Blackburn, Jr., Director of Circulation

NUCLEONICS (with which is consolidated "Atomic Power" and "Atomic Engineering") April, 1954, Vol. 12, No. 4. Publication Office: 212 East York St., York, Pa.; Editorial, Advertising and Circulation Offices: 330 W. 42nd Street, New York 36, N. Y. Published monthly by McGraw-Hill Publishing Company, Inc. Entered as second class matter December 17, 1947, in the Post Office at York Pa., under the act of March 3, 1879.

Copyright 1954 by McGraw-Hill Publishing Company, Inc. All rights reserved.

Donald C. McGraw, President; Willard Chevalier, Executive Vice President; Joseph A. Gerardi, Vice President and Treasurer; John J. Cooke Secretary; Paul Montgomery, Senior Vice President, Publications Divisions; Ralph B. Smith, Vice President and Editorial Director; Nelson Bond, Vice President and Director of Advertising; J. E. Blackburn, Jr., Vice President and Director of Circulation. Allow at least one month for change of address. All communications about subscriptions should be addressed to Director of Circulation, 330 West 42nd Street, New York 36, N. Y. Price per copy $.75. Subscription rates, United States and U. S. Possessions $8 for 1 year, $12 for 2 years, $16 for 3 years. Canada $10 for 1 year, $16 for 2 years, $20 for 3 years. Latin America, $15 for 1 year, $25 for 2 years, $30 for 3 years. All other countries, $20 for 1 year, $30 for 2 years, $40 for 3 years. Member of ABC. Member of ABP.

NOW—the modern successor to the galvanometer

the new

ElectroniK

Null Indicator

electrical characteristics

INPUT IMPEDANCE
1500 ohms

CURRENT SENSITIVITY
0.6 x 10-9 amperes per millimeter

VOLTAGE SENSITIVITY
1 microvolt per millimeter

OPERATING VOLTAGE
115 volts, 60 cycles

If you use galvanometers, you'll be interested in the new *ElectroniK* Null Indicator. For here, at last, is the lab man's ideal d-c null balance detector . . . completely free from all the limitations of galvanometers.

It's easy to use—no "loss of spot" from excess signal; bridge balancing operation is simplified.

It's self-protecting—will take heavy over-loads without damage.

It's vibration-proof—undisturbed by nearby traffic or machinery.

It goes anywhere—needs no leveling or special mounting; plugs into 115-volt 60-cycle line; small case fits readily into experimental set-ups.

It's stable—holds steady zero after warm-up.

It's fast—indicates in less than one second; ideal for production testing.

It's sensitive—suitable for use with high precision measuring circuits.

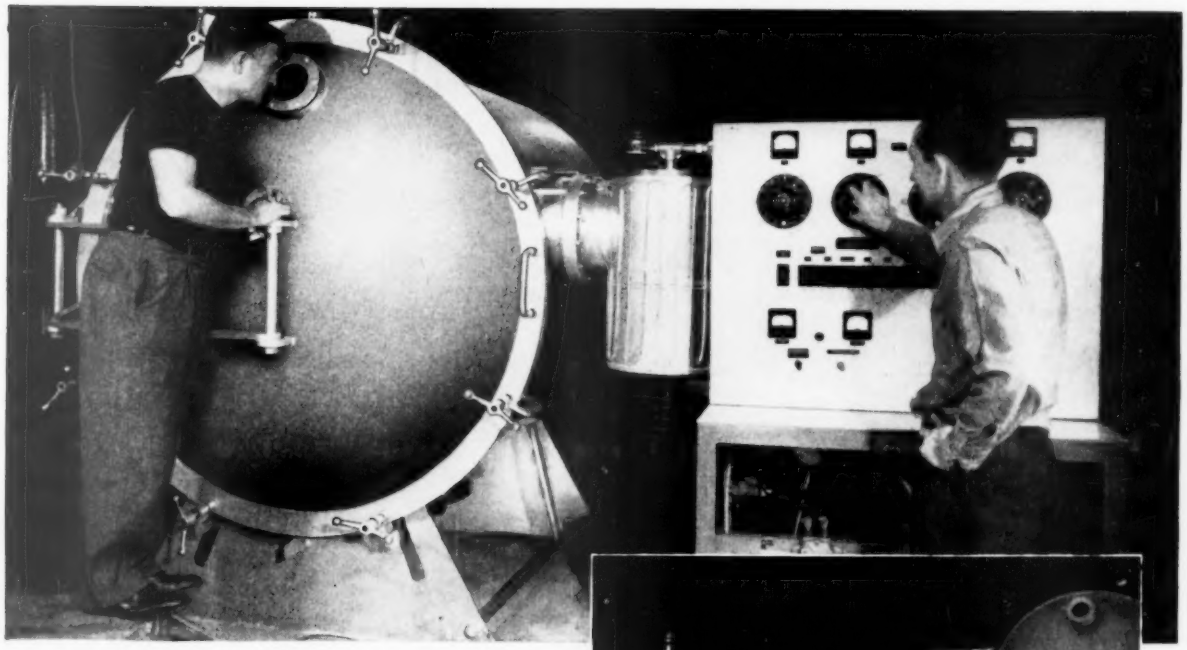
The *ElectroniK* Null Indicator is priced within reach of any budget. It will be a valuable asset to your lab. Write today for complete information.

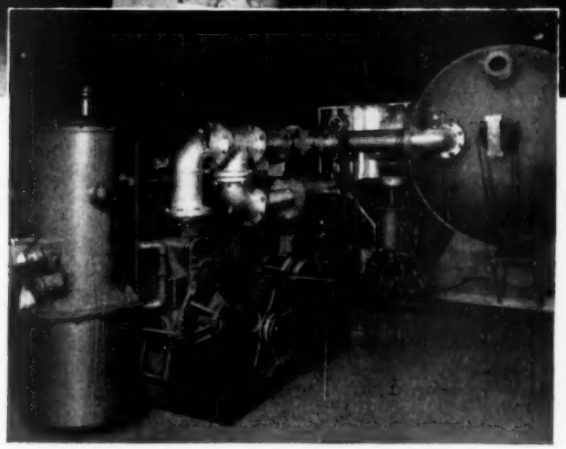
MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, Wayne and Windrim Avenues, Philadelphia 44, Pa.

● **REFERENCE DATA: Write for Instrumentation Data Sheet No. 10.0-12.**

MINNEAPOLIS
Honeywell
BROWN INSTRUMENTS
First in Controls

Want more information? Use post card insert in this issue.





Kinney High Vacuum Pumps (Models DVM 12.8.14 and VSM 5.5.6) are used on this machine — manufactured by Optical Film Engineering Company, Philadelphia, Pa. — for depositing coatings on precision optical lenses, jewelry, plastic novelties, and countless other products. The vacuum system employed by this processing package creates absolute pressures as low as 10^{-6} mm. Hg. With this fast system, processing is carried out within a few minutes after loading, insuring maximum output per hour. Many of these coating machines are serving industries throughout the country.

How to get the right vacuum pump

By consulting Kinney, you can choose from our line of 13 Single Stage and Compound vacuum pump models . . . the biggest, most versatile pump line on the market. We can help you size and apply these reliable high vacuum pumps to your vacuum processing operations. Our district offices are staffed with competent vacuum engineers, to assist you.

SEND COUPON TODAY!

KINNEY MFG. DIVISION
THE NEW YORK AIR BRAKE COMPANY
3614 WASHINGTON STREET • BOSTON 30 • MASS.

☐ Please send Bulletin V-51B describing the complete line of Kinney Vacuum Pumps.

Name .....
Company .....
Address .....
City ..... State .....

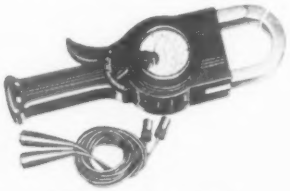
Want more information? Use post card insert in this issue.

Model 622 – Ultra-Sensitive Instruments

Portable d-c and a-c thermo instruments for precision measurement of potentials and minute currents in electronics or laboratory research.

Model 901
Portable Test Instruments

Available in d-c, Model 901 —and a-c, Model 904, single and multiple ranges of wide coverage. Excellent scale readability and shielding. Accuracy within ½ of 1%.



A-C Clamp Volt-Ammeter

(Model 633, Type VA-1) For convenient and rapid measurement of a-c voltage and current without breaking the circuit. Jaws take insulated or non-insulated conductors up to 2" diameter. Safe, rugged, versatile. Also available as a-c clamp ammeter, without voltage ranges.

Specialized and Multi-purpose

INSTRUMENTS

for

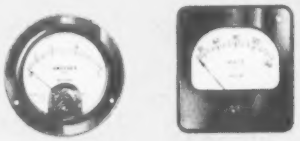
- **RESEARCH**
- **PRODUCTION**
- **MAINTENANCE**

For complex, or just routine measurement jobs, these and other specialized WESTON Instruments save time and assure dependable measurements. For information on the complete line, see your local Weston representative, or write . . . WESTON Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 5, N. J.

WESTON
Instruments

Sensitive Relays

A line of sensitive relays including the Model 705 which provides positive operation at levels as low as ½ microampere. Non-chattering magnetic contacts handle up to 10 watts at 120 volts.

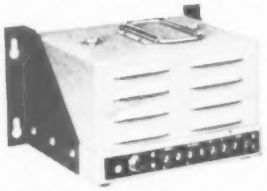


Panel and Switchboard Instruments

A complete line of instruments in all types, sizes and ranges required for switchboard and panel needs . . . including d-c, a-c power frequencies and radio frequency, rectifier types and D.B. meters.

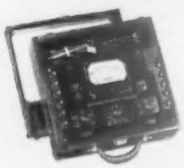
Model 697 Volt-Ohm-Milliammeter

One of a line of pocket-size meters, Model 697 combines a selection of a-c and d-c current, and resistance ranges. Ideal for maintenance testing and many inspection requirements.



Model 1411 Inductronic D-C Amplifier

Stable amplifier provides high degree of resolution even at fractional loads. Reaches steady full scale deflection in a fraction of a second. Interchangeable plug-in range standards for either microamperes or millivolts.



Industrial Circuit Tester – Model 785

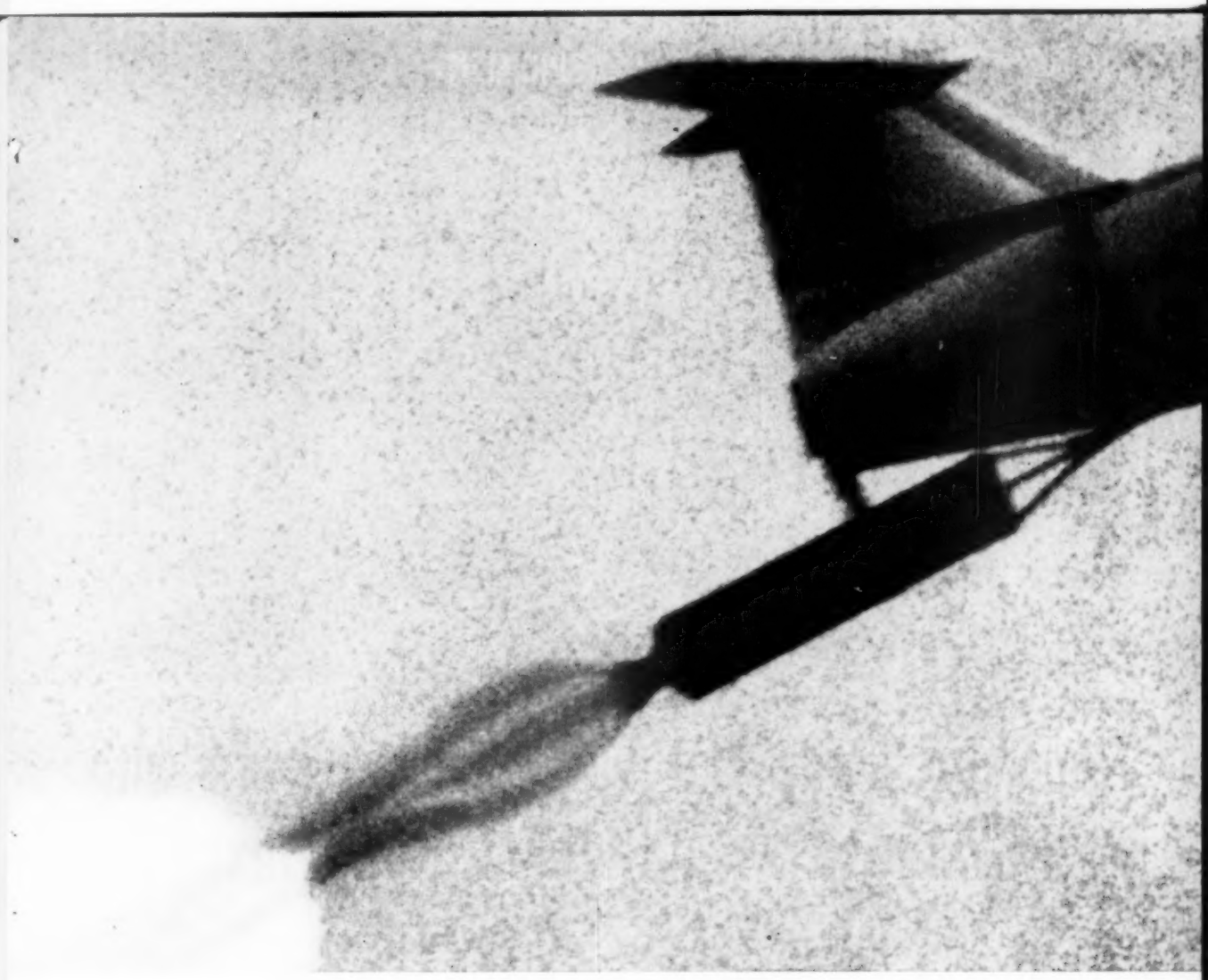
A multi-range, multi-purpose, ultra-sensitive analyzer, for laboratory and industrial checking of electrical and electronic circuits. Has 28 practical scale ranges; measures d-c and a-c voltage, d-c and a-c current, and resistance. Accessories available to extend ranges. Compact and portable; furnished in either oak or steel case.

Model 686
Electronic Tube Analyzer

Tests tubes under exact operating potentials. Accurately determines true mutual conductance of all tubes, In accordance with manufacturers' rated operating conditions, or under special operating conditions.

High Frequency Electronic Analyzer
Model 769

A three-in-one instrument providing a self-contained Volt-Ohm-Milliammeter, a high impedance electronic D-C Volt-Ohmmeter, and a probe type Vacuum Tube Voltmeter for use to 300 megacycles. Exceptionally stable and accurate. Has specially designed extremely small RF and D-C probes.



moment in history

You are looking at 1/1000 of a second in the history of aviation. It occurred at a fraction past 4:31 p.m. on January 20, 1949.

This was the Zero moment which marked the official launching of the first successful pilotless bomber to be approved by the U.S. Air Force—the Martin B-61 Matador.

The picture is historic for a very significant reason: it records the tradition-shattering payoff of an entirely new development in the aircraft industry, known as Martin Systems Engineering. This is a science and a method of developing spaceborne systems as total solutions of Operations problems.

The Martin Matador is far more than the thing you glimpse here. Behind it is an integrated network of facilities designed to give this important new weapon simplicity of operation and extreme mobility. These components add up to the total solution of one of the most formidable security problems of our time.

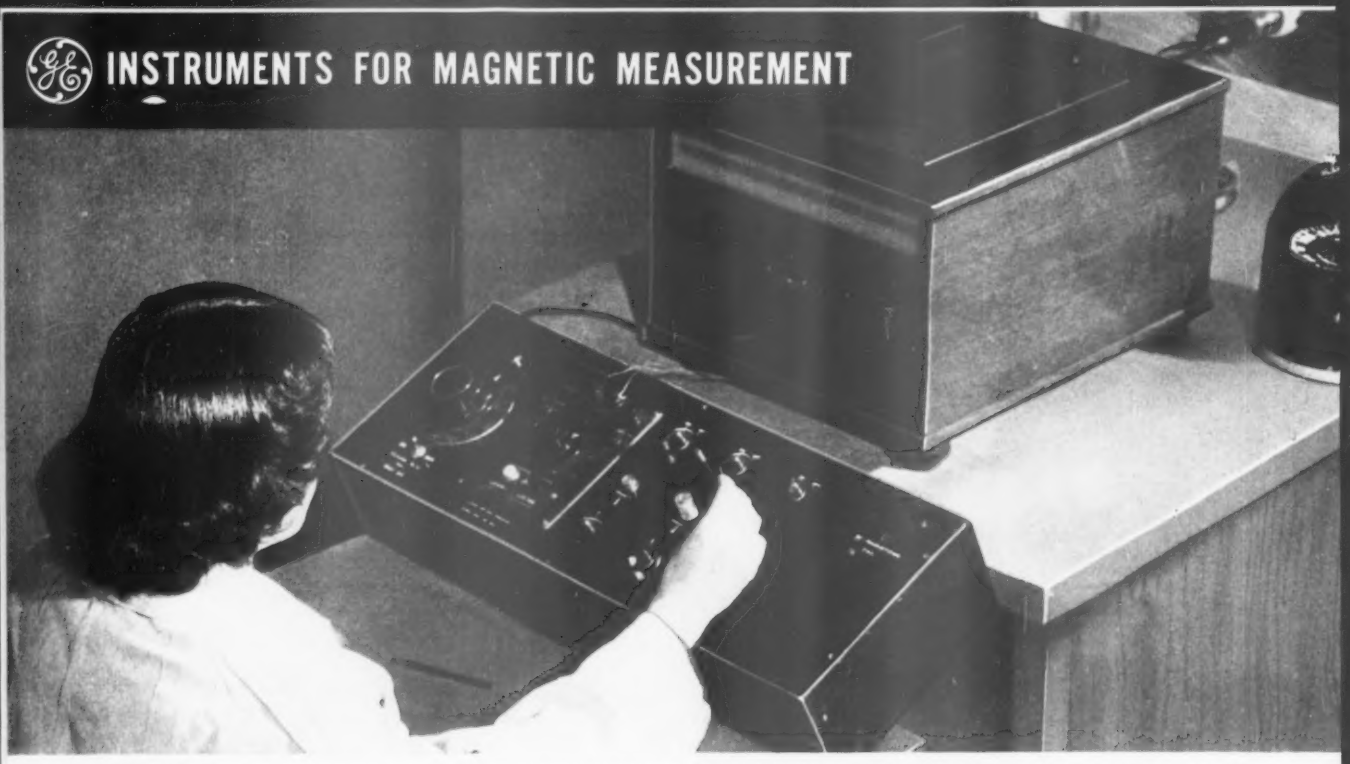
They also add up to one of today's most important developments: the full story of Martin Systems Engineering.

You will hear more about Martin!

Martin AIRCRAFT

THE GLENN L. MARTIN COMPANY
BALTIMORE · MARYLAND

INSTRUMENTS FOR MAGNETIC MEASUREMENT



HIGHLY VALUABLE IN MEASURING FLUX, THE INDICATING FLUXMETER IS ALSO USEFUL IN TIME INTEGRATIONS OF TRANSIENT VOLTAGE.

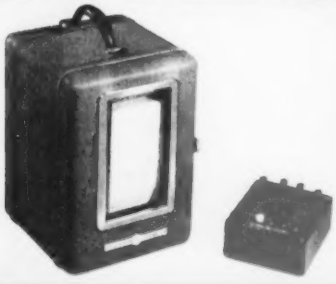
Eliminate Costly Flux-measurement Errors with Highly Sensitive G-E Indicating Fluxmeter

Three outstanding features of the General Electric indicating fluxmeter combine to provide dependable magnetic measurement:

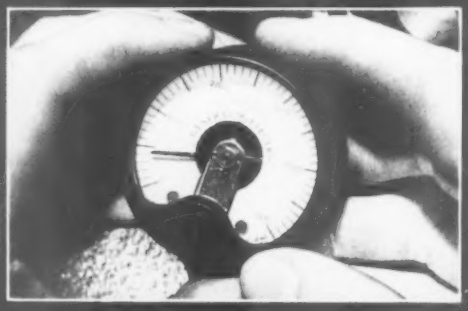
1. **THE INSTRUMENT** is extremely accurate; ±1% of full-scale deflection.
2. **UNUSUALLY HIGH** sensitivity of 1 millimeter deflection per 100 flux lines is readily obtainable.
3. **AN EXTERNAL CONTROL BOX** provides compensation for small extraneous voltages.

Price of the equipment, including control box, is $278.50.* A separate unit for calibration of the instrument over a wide sensitivity range is $58.50.*

RECORDING FLUXMETER



GAUSS METER



BULLETIN AVAILABLE

SECTION A605-79
GENERAL ELECTRIC COMPANY
SCHENECTADY, N. Y.

Please send me a copy of your Bulletin GEC-777, "Equipment for Measuring Magnetic Properties."

NAME .....

COMPANY .....

ADDRESS .....

.....

COMBINING THE ADVANTAGES of the indicating fluxmeter with those of a G-E strip-chart recorder, the recording fluxmeter is priced at $780.00.*

*Manufacturer's suggested retail price.

CONVENIENT, POCKET-SIZE gauss meter facilitates checks of flux density and direction in magnetic gaps. Ideal for use in small or conjested areas. Price with reference magnet, case, $67.10.*

FOR FURTHER DETAILS about these instruments, simply send in coupon, or contact your nearest G-E Apparatus Sales Office.

GENERAL ELECTRIC

NUCLEONICS

APRIL, 1954

Jerome D. Luntz, *Editor*

Research Reactors

What You Need To Know To Build One

About the cover 12
AEC Policy 8
What the Contract with AEC Calls For 9
What a Reactor Can Be Used For 11
Status of Reactor Projects 11
Technical and Cost Data for Reactor Design 12
Reactors vs Other Nuclear Machines 14
Secrecy 15
Safety Problems 16

IF NOT NOW, then soon, nuclear reactors will be considered indispensable to research and educational programs. Their main uses are: for training, as neutron sources, to produce radioisotopes, and for irradiation work.

Up until last year, the only reactors in this country were owned by the government and were on government sites. Thus the problems of building reactors on university campuses were never confronted. This meant that the pioneer on such projects, Clifford Beck of North Carolina State College, had to suffer because of this lack of precedent and the consequent need to plow through government red tape.

Questions had to be answered on such matters as: lending of fissionable material, reactor safety, financial and legal responsibility, etc. The Atomic Energy Commission had to formulate a policy on these points and on such things as what to do if a flood of universities requested fuel for reactors.

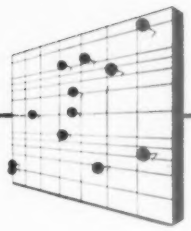
Both Dr. Beck and the AEC are to be congratulated. As a result of this first experience there now exist an AEC policy and a procedure that take into account most situations. Actually AEC is now encouraging university reactor projects (and the AEC general manager has so advised the personnel of the AEC operations offices).

There is no doubt that new problems will arise as, for example, when institutions request permission to build reactors of higher power levels and different designs than thus far approved. Legislation is being requested to increase the amount of fissionable material that can be lent to universities. At present, a school wanting 1 kg or more of enriched uranium requires that an AEC employee be in residence at the institution as the custodian of the fuel.

In any event, it's quite clear that any organization that has a serious interest in obtaining a reactor, that has the funds, and that has a well-conceived reactor design and program can get permission to build the reactor.

And to make it all easier there are now upwards of a dozen industrial firms that are seeking the business of designing and building these machines, and are available for expert advice.

To assist groups in getting into this field, NUCLEONICS presents the special report on the next nine pages. It is based on material presented at a conference at Oak Ridge, Feb. 17 and 18, sponsored by Oak Ridge Institute of Nuclear Studies and Oak Ridge National Laboratory in cooperation with the National Research Council.



AEC Policy

By THOMAS H. JOHNSON
Director, Division of Research
U. S. Atomic Energy Commission
Washington, D. C.

WITH THE INCREASING INTEREST of universities and other research institutions in acquiring research reactors, the Atomic Energy Commission has adopted a uniform policy for dealing with institutions requesting the loan of fissionable material for use in reactors for independent research and training.

The Commission will loan fissionable material, without charge for rental or processing, when this material is not in immediate demand for military or other use by the Commission, provided the Commission is assured that:

a. The institution has a financial plan which adequately provides for the construction of the reactor and for its continued operation for a reasonable period of time.

b. The design and operation of the reactor will be in the hands of responsible and technically competent people.

c. The reactor will be used in a well conceived research program which may be expected to contribute significantly to the training of students in nuclear research, engineering, or other fields of science.

d. The loan meets the requirements of the Atomic Energy Act and regulations of the Commission as regards the amount of material, security, classification, accountability, and health and safety.

Fuel

Fissionable material is in sufficient supply to permit some allocation for research. The AEC has already made a loan of 999 grams of U^{235} to North Carolina State College; and Penn State University has been assured that up to 4 kg will be made available when its reactor is constructed.

The law restricts the distribution of fissionable material (a) to such quantities, and to loans on such terms, that no applicant will be enabled to obtain an amount sufficient to construct a bomb or other military weapon; (b) to applicants who are equipped to observe, and who do not fail to observe, such health and safety standards as are, or may be, established by the Commission; and (c) to an extent which will not prevent the Commission from making such provision for its own needs and for such conservation of fissionable material as it may determine to be in the national interest for the future development of atomic energy. Except for transfers to the military under Presidential directive, all fissionable material must remain under the ownership of the Commission and be subject to recall when needed by the Commission.

These restrictions may limit the size or power level of reactors which can be independently operated; they will require rather rigid specifications on operating procedures and on features of the structure and equipment which have a bearing on health and safety; and they may limit the number of reactors which can be built in any year.

The principal obstacles to the offsite construction of reactors have been: first, the uncertainty that a reactor can be safely operated on the average college campus. Recent tests, relevant to the swimming pool reactor, when they have been fully evaluated, may give the necessary assurance that some reactors can be operated safely at the desired power levels. The North Carolina reactor and the Penn State reactor have been carefully considered by the AEC Advisory Committee on Reactor Safeguards and were judged to be safe under the operating procedures proposed. The second obstacle has been the legal restriction on the amount of fissionable material. It would take legislative action to remove this restriction and permit the outright loan of amounts of fissionable material sufficient for the operation of some desirable reactor types. Under the present law, however, it would be possible to allocate material under the custodianship of an AEC employee.

Financing

It is evident that the benefit of unorthodox thinking might not be fully realized if the university reactor were operated under contract with the Commission. In research and education, as in industrial development, there is great virtue in encouraging the use of private capital for making an independent approach to the problems of atomic energy. It is therefore the intent of the Commission to limit the use of its funds to the bare minimum needed to insure an adequate annual increase in the number of independent reactors to keep pace with the growing interest in atomic energy, and at the same time to restrict their installation to those institutions which have the determination, the resources, and the technical competence needed for their successful operation and efficient utilization. The aims of the program will be best served if all of the costs of construction of the associated buildings can be met by the institution without financial help from the Commission. Many of the advantages of an offsite reactor program would appear to be lost if the Commission were to contribute a major share of the costs of such projects. Subject to the availability of funds, the Commission will consider partial support of the construction of reactors at nonprofit institutions.

Independence in operation is even more desirable than in construction. Normally the Commission would not supply fissionable material for an independent reactor if its operation were foreseen to depend upon AEC support.

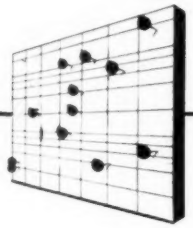
Several basic reactor designs, suitable for research purposes, have been demonstrated in AEC laboratories. Minor variations in design of any of these reactors could be made to meet special requirements, but an institution would not be encouraged to embark upon a radically new design of its own since this approach might run into un-

desirable classification, as well as potential technical difficulties.

While it is anticipated that programs will be conducted as far as possible on an unclassified basis, conditions may exist or may develop in such a way as to require the application of security measures for the protection of information and material, including the clearance of personnel and the establishment of appropriate physical barriers and provisions for the guarding of areas and materials commensurate with the degree of security interest present. In any case at least one individual associated with a university reactor project, designated as the security monitor, must be cleared for access to "Restricted Data" and thoroughly indoctrinated in Atomic Energy Commission security requirements.

The Commission must assure itself that fissionable material would not fall into the hands of unauthorized persons. Since material loaned for a reactor would be inside the shield and, after initial use, highly radioactive, reasonable measures taken to safeguard the instruments and equipment in the reactor building would provide adequate protection for the reactor core.

A statutory provision states that "the Commission shall not distribute material to any applicant and shall recall distributed material from any applicant who is not equipped to observe or who fails to observe such safety standards to protect health and to minimize danger from explosion or other hazard to life or property." Therefore the Commission must be assured at all times that the operation of the reactor does not involve unusual hazards to life and property either on the site or in the environs. The design of the facility, and the operating and radiation safeguard procedures would therefore be subject to the inspection and approval of the Commission. Exposure tolerances and means of monitoring radiation should conform with the standards approved by the Commission. Moreover, in the agreement under which the material is loaned there should be no implication of responsibility on the part of the Commission for damages to life or property resulting from the operation of the reactor.



What the Contract with AEC Calls For

By HERMAN M. ROTH
Oak Ridge Operations Office
U. S. Atomic Energy Commission
Oak Ridge, Tennessee

AN INSTITUTION desiring a research reactor first comes in official contact with the Atomic Energy Commission when it obtains a study contract. This contract provides for the institution to design a reactor, to make a hazards study of the operation of the reactor at the proposed site, and to develop an operational plan, including security, for the operation of a reactor. Excluding the study contract period, the AEC Operations Office comes into the picture once the decision in principle has been made to lend fissionable material. By this time the institution has a broad picture of a type of reactor it wishes and has made a study of the hazards involved and has received concurrence of the Advisory Committee on Reactor Safeguards and is proceeding to undertake detailed designs.

The Operations Office then undertakes to assure that all of the requirements of the Atomic Energy Act and special requirements placed on the tentative approval by the Commission are carried out. Further that any data or further study required by the Safeguard Committee is supplied by the university or college and presented to the Committee, that provisions have been made for continuing study and observation of radioactive hazards, that the security groups are brought in to review and approve the security plans for the fissionable materials and that the operating plans include sufficient information to assure safe operation. They are not necessarily done in this order.

In the meantime, the Operations Office negotiates a contract with the institution. This contract, of course, must be acceptable to the college and, at the same time, permit the Commission to carry out its responsibilities under the Atomic Energy Act.

In the negotiation of a contract, the first consideration is conformance with existing law. Then, any restriction or limitation in the contract that would retard the research and development program must be avoided if at all possible since we would be defeating our own purpose. We do not wish to get into the institution's business more than we have to in order to carry out the provisions of the Atomic Energy Act.

Contracts are written in various ways, depending on the attorney making the draft. I should like to approach this subject from a simple point of view: (1) What the Commission will do. (2) What strings are attached. (3) What the institution will do. It is realized that there will be some overlap.

What the Commission agrees to do:

We furnish the fuel—thus far it has been uranium in the weight and composition required. In general, the Commission agrees to furnish the fuel in a form suitable for direct insertion in the reactor, without additional processing or fabrication by the institution. In the case of uranyl sulfate, it was desirable to furnish a more concentrated fuel and perform dilution at the site. This would not be necessary for metal fuel elements, since they may be fabricated in the form suitable for direct loading. The use of existing designs of reactors usually implies that the Commission has the facilities for providing the fuel in

the form requested. This point should be checked before proceeding too far along with your design.

It is not expected that institutions will undertake chemical processing of the fuel. Hence, the Commission considers the need for replacement of fuel in the initial proposal. In general, of course, the rate of burnup is dependent on the reactor power level. For low power levels, the Commission will consider replacement as a new loading and since we furnished the fuel in the first place, we will either furnish new fuel or reprocess the old. As the program progresses and if higher power levels are approved, other considerations may enter the picture.

We furnish an analysis of the material.

We will process any wastes contaminated with fissionable materials, at the institution's expense, if such charges are appropriate.

We continue to provide information as required to keep the security monitor up to date on classification, arranging for visits to Commission installations, either classified or unclassified, as required by the research and development program.

We furnish appropriate security guards for the transportation of the fuel to the institutions' site, at the institution's expense.

Those materials or services for which the Commission is the only source are furnished at cost.

Strings attached:

The fuel may only be used in the reactor as planned for research and development purposes as defined in the Act and for medical therapy.

Any fissionable material made during the process of operating the reactor becomes the property of the Commission. The fission products which are recovered in the process of decontaminating the fuel also become the property of the Commission. Of course the new fissionable material produced in low-power, enriched-fuel reactors will be small. However, if normal or slightly enriched uranium is used at higher power levels, the recovered fissionable materials may be comparable to the fuel burned.

Irradiation of materials, other than the fuel, that result in fissionable materials being produced, is forbidden without the prior written approval of the Commission. The irradiation of explosives is also forbidden without the prior written approval of the Commission.

The Commission retains patent rights to the extent determined by Commission and Executive policy of the government.

The institution agrees to:

Observe such safety standards and instructions, including the power level of the pile operation, as agreed to be necessary to protect health and minimize danger to life and property.

Comply with instructions on accountability. For fabricated fuel elements, this is very simple. Someone must count the number of fuel elements on hand periodically and assure himself that they are the ones actually furnished by the Commission. For liquid fuels, there is a little more difficulty. The Commission does not require any more information than that necessary for good reactor operation.

Accept the responsibility for the operation of the reactor and those monitoring activities which are included in the operation plan of the reactor which has been approved by the reactor safeguard committee.

Monitor the activities from the security point of view and not disclose any classified information to unauthorized persons.

Accept the classification of information as directed by the Commission. However, if the operation should become classified, continuation would be subject to mutual agreement.

Appointment of a project director and an assistant project director, subject to the approval of the Commission.

Health and Safety

Another part of the administration of these contracts is the so called orders and regulations. Under Section 10c of the Atomic Energy Act the Commission is charged with the responsibility of issuing appropriate orders to protect the health and safety of personnel. Some standards and instructions governing the possession and use of fissionable materials can be made in the contract. These provisions are those which have the element of mutually advantageous considerations and mutual agreement. The orders or regulations, however, take the form of directives and, in a sense, Federal regulations. As a minimum penalty, failure to comply could form the basis for withdrawal of the material.

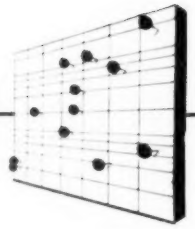
These statements may sound foreboding. In actual practice, the institution is directed to do those things which in general it has already agreed to do. However there are a few limitations. The first of these is a limitation on significant changes in any features of the reactor facilities without the approval of the Commission. The institution is also directed to operate under a reduced power level or curtail operations entirely if the actual operation discloses the inadequacy of any feature to assure safe operation, unless approval is obtained from the Commission.

A second point is that the production and distribution of radioisotopes must conform with and tie into the Commission's radioisotopes procedures. I should like to discuss this in three parts: (1) production, (2) use in the contractor's facilities, and (3) distribution outside.

Under production, the institution has the previously mentioned limitation on the production of fissionable materials; thus the irradiation of uranium (other than that in the fuel) and thorium is prohibited. From a safety angle the irradiation of explosives is prohibited unless specifically authorized. Further, at the moment, gem material irradiations are prohibited. There are no prohibitions that limit the experimental work per se.

The second point—the use of the radioisotopes in the institution's facilities—is governed by the issuance of a general authorization to use radioisotopes similar to those issued to the Commission's own laboratories.

The third case, the transfer of radioisotopes to others, normally involves direct contact with the Isotopes Division. It is the present law of the land that, except for certain small quantities, no one can possess or use radioisotopes without appropriate authorization. Hence prior to the shipment of any isotopes off the institution's site, the institution must assure itself that the receiver has an authorization to possess and use the isotopes.



What a Reactor Can Be Used For

Los Alamos Scientific Laboratory has had a water boiler reactor in operation since 1944. L. D. P. King, responsible for much of the development of the reactor, lists the following as illustrations of the many experiments done with it:

A. Reactor Technology

The first group of experiments was done to study the characteristics of the reactor as such. They are also very useful in giving personnel experience with radiation and the methods used for detecting and counting neutrons and gamma rays.

1. Approach to critical—multiplication studies
2. Control rod calibrations
3. Critical behavior—reactor period as a function of excess reactivity
4. Temperature coefficient measurements—the effect of temperature on reactivity
5. Neutron flux distributions
6. Neutron energy distributions using a chopper for slow neutrons and photographic plates for fast neutrons
7. Shielding studies

B. Physics

The largest series of experiments has been devoted to fundamental experiments in the field of physics. This is partly due to the fact that the reactor was run by a group in the physics division. A few of the many experiments are mentioned below.

1. Studies of the fission process
   - a. Neutron energy distribution from the fission of U^{235} by observing proton recoils.
   - b. Observations on the number and periods of neutrons and gamma rays appearing after fission by shooting fissionable samples through the reactor "glory hole."
   - c. Search for triple fission by using a large special triple coincidence chamber directly in the large cavity of the thermal column.
   - d. Determination of the total energy of fission by placing a calorimeter with an internal sample of U^{235} in the thermal column.
   - e. Measurement of the velocity distribution of the fission fragments by measuring the time of flight of the fragments.
2. Examples of neutron cross-section measurements
   - a. Total cross section of He^3 for slow neutrons using a graphite filtration technique to change the neutron energy. Absolute values are obtained by a comparison with a known boron sample in an identical geometry.
   - b. Total cross section for large number of elements by using a neutron converter in the "glory hole" as a fast neutron source and a proton recoil chamber as a neutron spectrometer itself. Samples of gaseous products can be obtained directly from the gas circulating system. Particular isotopes can be emphasized by making use of their half-lives, i.e., by taking the sample from the exhaust line close to, or far from, the reactor.

   Small amounts of the reactor solution itself furnish excellent sources of rare isotopes. Here certain products can be emphasized by the previous running history of the reactor.

C. Biomedical Research

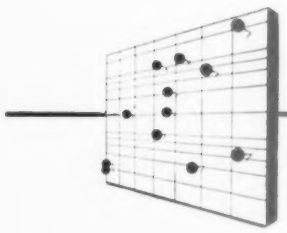
One reactor application to biology and medicine is an experiment to determine the biological effectiveness of thermal neutrons and hard gamma rays.

Status of Reactor Projects

Institution	*Reactor type*	*Status and remarks*
Columbia	Swimming pool	Financing incomplete
Utah	Water boiler	Reactor designed; power >100 kw; flux, 3 or 4 × 10^{13} n/cm²/sec; financing incomplete
Penn State	Swimming pool	Approved by AEC, work under way; scheduled to be in operation by mid-1955; total facility cost $300,000; power 100 kw
North Carolina	Water boiler	In operation 9/53
Michigan	Swimming pool	Up for approval before Reactor Safeguard Committee; power, up to 1 megawatt; flux, 10^{13} n/cm²/sec
UCLA	Water boiler	For medical school; financing incomplete
Watertown Arsenal	Swimming pool	Being designed under industrial contract
Naval Research Laboratory	Swimming pool	Design complete; construction of building to be started shortly; power 100 kw
Vanderbilt	Swimming pool	Financing incomplete
Wright-Patterson Air Force Base	Swimming pool	To be designed by industry; power 100 kw

NOTE: Other universities reported to have an interest in obtaining a reactor are: Ohio State (approved by board of trustees in Feb.), Alabama Polytech; Case; Connecticut; and Texas.

Industrial organizations known to be interested in design, engineering and/or construction of research reactors are: American Machine and Foundry, Babcock and Wilcox, Bendix Aviation, Foster Wheeler, General Electric, Kaiser Engineers, Walter Kidde, North American Aviation, Nuclear Development Associates, Vitro.



Technical and Cost Data for Reactor Design

By J. A. LANE
Oak Ridge National Laboratory
Oak Ridge, Tennessee

ALTHOUGH THE NUMBER of nuclear systems that might be used in the design of a research reactor is practically unlimited, experience has shown that some systems are superior from the standpoint of safety, reliability and cost. These types have the common characteristic of being fueled with enriched uranium and are water cooled.

Other types, such as the air-cooled natural uranium piles, appear to be significantly less attractive as high level sources of neutrons for research. This is mainly because of their inherently high cost per unit of flux. It is of interest, however, to compare the characteristics of natural uranium research reactors with the types using enriched fuels. The properties of natural uranium research reactors are shown in Table 1.

The widespread use of enriched uranium as fuel for research reactors is shown in Table 3. There are five systems: (a) solid fuel, heavy water; (b) solid fuel, light water; (c) liquid fuel, light water; (d) homogeneous graphite; and (e) liquid fuel, heavy water. This latter type offers some advantage, but has not yet been used as a research reactor because of development problems.

Performance and Costs (see *Front Cover*)

A comparison of the performance of various systems measured in terms of the specific power and thermal neutron flux is shown in Table 4. The approximate cost of the reactors is also shown, not including fuel costs. It is evident that not only is the absolute performance improving with time, but also the flux level per unit of construction cost. Plotting this performance index as 10^{12} flux units per megabuck against the start-up date indicates a definite upward trend for the majority of systems. This is shown on the front cover.

Breakdown of Costs

Although one can argue that the performance index shown, measured in terms of total dollars spent, is not a fair comparison of the various reactor types since in most cases only a small fraction of the cost went toward cooling (i.e., providing high flux), a breakdown of costs of even the extreme cases indicates that approximately the same fraction of the cost went into cooling. This is shown in Table 2.

It is clear that certain inherent characteristics of the various systems dictate performance rather than the cost of facilities other than the cooling system. For example, the natural U-graphite reactors are of necessity large. In the case of the Brookhaven reactor, the cost of the graphite alone amounted to approximately $2,000,000. Fuel, if it were considered, would add another $4,000,000.* This may be compared with costs less than $100,000* for the fuels in the enriched systems with no cost for the water moderator. In addition, the large size and high fuel inventory of graphite-moderated systems considerably reduce the flux for a given power level.

Comparison of Enriched Systems

For enriched-fuel, water-moderated reactors, it is of interest to determine the maximum flux that one gets for a given cost of moderator and cooling system. The following four systems are considered:

1. light water, solid fuel
2. light water solution (homogeneous)
3. heavy water, solid fuel
4. heavy water solution (homogeneous)

If one sets a limit, say $250,000, to be spent for D_2O and the heat removal system, the thermal neutron flux for these four systems will vary with the diameter of the reactor core. This variation is shown in Fig. 1, which takes into consideration the change in fuel concentration and the amount of moderator for the stated conditions. As a basis for the comparison, the cost of D_2O has been

* Based on W. H. Zinn, NUCLEONICS **10**, No. 9, 8 (1952)—U^{235} at $35/lb and U^{238} at $20/gm.

TABLE 1 Research Reactors Fueled with Natural Uranium

Designation	*Date*	*Fuel (tons)*	*Moderator*	*Power level*
CP-1	1942	6 U metal 40 U oxide	385 tons C	100 watts
CP-2	1943	10 U metal 42 U oxide	472 tons C	2 kw
X-10	1943	35 U metal	620 tons C	3800 kw
CP-3	1944	3 U metal	6.5 tons D_2O	300 kw
NRX	1947	10 U metal*	17 tons D_2O	30,000 kw
BNL	1950	60 U metal*	700 tons C	28,000 kw

* Calculated from published data.

TABLE 2 Cost Breakdown of ORR, MTR and X-10 Reactor

Item	*Millions of dollars* ORR	MTR	X-10
Site	—	2.1	—
Reactor	1.4	5.9	2.7
Building	0.6	3.5	1.1
Water system	0.4	3.1	—
Air system	0.1	0.3	0.9
Power plant	—	1.0	—
Design, etc	0.3	2.1	0.5
	2.8	18.0	5.2
Fraction assigned to cooling system	17%	18%	18%

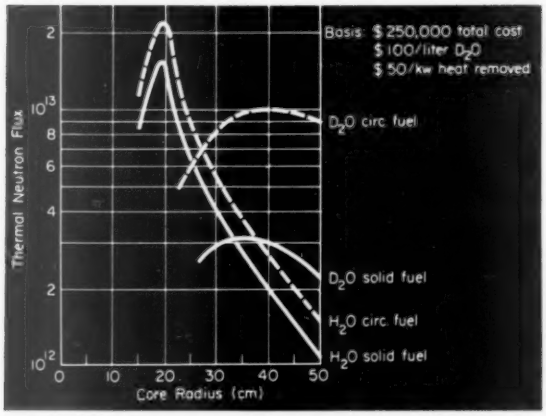


FIG. 1. Flux of enriched reactors with fixed cooling costs

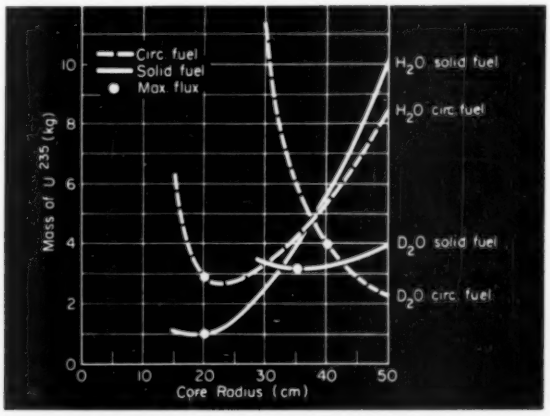


FIG. 2. Enriched fuel required for reactors (fixed cooling costs)

TABLE 3—Research Reactors Fueled with Enriched Uranium

Designation	*Date*	*Enriched U^{235} fuel*	*Moderator*	*Power level*
Heavy-water type				
CP-3′	1950	4 kg U + Al	7 tons D_2O	300 kw
CP-5	1953	1.2 kg U + Al	6.5 tons D_2O	1000 kw
Water boilers				
LOPO	1944	0.5 kg UO_2SO_4	H_2O	<1 watt
HYPO	1944	0.8 kg UO_2SO_4	H_2O	6 kw
SUPO	1951	0.8 kg UO_2SO_4	H_2O	45 kw
No. Carolina	1953	1 kg UO_2SO_4	H_2O	10 kw
MTR type				
LITR	1950	3 kg U + Al	H_2O	2000 kw
BSF	1951	2.5 kg U + Al	H_2O	100 kw
MTR	1952	4 kg U + Al	H_2O	30,000 kw
ORR (scheduled)	1956	2.5 kg U + Al	H_2O	5000 kw
Homogeneous graphite				
NAA low power	—	3.2 kg U_3O_8	graphite	160 kw

TABLE 4—Performance and Cost of Research Reactors

Reactor	*Date*	*Specific power (kw/ton of fuel)*	*Avg. thermal neutron flux*	*Cost ($\times 10^6$)*
CP-1	1942	0.002	4×10^8	1.5
CP-2	1943	0.04	1×10^8	2.0
X-10	1943	110	5×10^{11}	5.2
CP-3	1944	100	5×10^{11}	2
HYPO	1944	7,000	1×10^{11}	0.5
NRX	1947	3,000*	2×10^{13}	10
CP-3′	1950	68,000	2×10^{12}	2
BNL	1950	470*	2×10^{12}	20
LITR	1950	500,000	1×10^{13}	1
SUPO	1951	50,000	1×10^{12}	0.5
BSF	1951	37,000	1×10^{12}	0.25
MTR	1952	7,000,000	2×10^{14}	18
NCSR	1953	9,100	2×10^{11}	0.5
CP-5	1954	910,000	2×10^{13}	3
ORR	1956	1,800,000	5×10^{13}	2.8
NAA	—	45,000	1×10^{12}	1.4

*Calculated from published data.

REACTOR ALPHABET

CP-1, CP-2, CP-3, CP-3′, CP-5—various reactors at Argonne

X-10—Oak Ridge

HYPO, SUPO—Los Alamos

NRX—Chalk River

BNL—Brookhaven

LITR—low intensity test reactor, Oak Ridge

BSF—bulk shielding facility, Oak Ridge

MTR—materials testing reactor, Idaho

NCSR—Raleigh

ORR—conceptual design of a reactor for basic research using advanced MTR technology; does not refer to a specific reactor project

NAA—North American

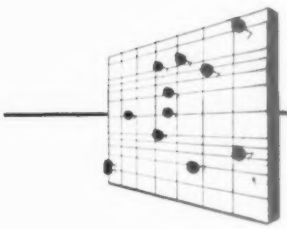
assumed to be $100/liter. This has been estimated by manufacturers to represent a future free market value for D_2O. The cost of the heat removal system has been taken at $50/kw heat. In the case of the circulating solution reactors, the external system holdup has been assumed to be 20 liters per Mw heat for a closely coupled system. Fuel costs are not included in the comparison, but are approximately the same in all cases of interest.

Figure 1 shows that circulating solution D_2O reactors have a considerable advantage in terms of thermal flux obtainable compared to other systems. The present development of homogeneous reactors at Oak Ridge may well lead to the use of this system for high neutron flux research. Material requirements are shown in Fig. 2.*

Safety

The importance of a high degree of safety and reliability in a research reactor is obvious. The water systems are characterized by a strong negative temperature coefficient and ability to shut down automatically on loss of coolant. This has been demonstrated experimentally in a number of reactors of this type. The light-water cooled graphite-moderated or heavy-water-moderated reactors do not necessarily possess this feature and, depending on the particular design, may not be inherently as safe as the heterogeneous or homogeneous water reactors.

* The minimum U^{235} requirements per unit of flux (10^{12} n/cm²/sec) are: H_2O-solid fuel—0.07 kg; H_2O-circ. fuel—0.14 kg; D_2O-circ. fuel—0.40 kg; and D_2O-solid fuel—1.03 kg.



Reactors vs Other Nuclear Machines

According to how much money an institution has to spend and according to what its objectives are, a reactor or some kind of accelerator would be dictated. Here, for four price ranges, is a self-explanatory analysis by A. H. Snell, Oak Ridge National Laboratory, of the factors involved in a decision on what to buy.

$50,000-$100,000

Machine	"Rating"	Special building?	Versatility rating	Pedagogical rating	Performance rating
"Cockcroft Walton"	Several ma at 600 kev	No	A	A	B
Electrostatic generator	1.5 to 2 mv electrons or $^+$ ions	No	A	A	B
Cyclotron	18-in. 3 Mev H^+ or D^+	No	B	A	B
Betatron	25 Mev	No	C	B	B$^+$
Linear accelerator	12 Mev electrons	No	C	B	B
Reactor	1 kw cont. 10 kw flash 10^{10}-10^{11} slow flux	Yes	C	B	A

$100,000-$300,000

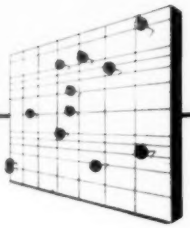
Machine	"Rating"	Special building?	Versatility rating	Pedagogical rating	Performance rating
Electrostatic generator	3 mv positive ions	No	A	A	B
Cyclotron	6 Mev H^+ or D^+	Marginal	A	A	B
Betatron or Synchrotron	75 Mev electrons	Yes	B	B$^+$	B
Reactor	10^{13} slow flux (swimming pool)	Yes	B	B	A
Linear accelerator		Insufficient experience			

$300,000-$750,000

Machine	"Rating"	Special building?	Versatility rating	Pedagogical rating	Performance rating
Electrostatic generator	5-6 mv	Vert: yes Hor: marginal	A	A	B
Cyclotron	40-in. 10 Mev D^+ 15 Mev H^+	Preferable	B	A	B
Synchrotron	200 Mev electrons	Yes	B	B	B
Reactor	10^{13} slow flux (water boiler)	Yes	B$^+$	B	A
Linear accelerator		Insufficient experience			

$750,000-$1,500,000

Machine	"Rating"	Special building?	Versatility rating	Pedagogical rating	Performance rating
Electrostatic generator	9 mv	Yes	A	A	B
Cyclotron	60-in. 20 Mev H^+ or D^+	Yes	A	A	B
Synchrotron	350 Mev electrons	Yes	B	B	B
Reactor	10^{13} slow flux LITR or NAA design	Yes	A	B	A
Linear accelerator		Insufficient experience			
Strong-focusing electron or proton synchrotron		Insufficient experience			



Secrecy

By J. G. BECKERLEY
Director, Office of Classification
U. S. Atomic Energy Commission, Washington, D. C.

THE BASIC PREMISE in declassifying information related to university research reactors has been that for effective use of a reactor in research it is necessary to have the maximum possible access to technical data on the reactor per se. It is difficult to see how a reactor could be put to best use if all that were available were bits of information such as: "Push button A; then if shutter omega is opened to position 4, there will be available a flux of 10^{10} thermal neutrons/sec/cm.^{2}" Of course, it could be done this way. However, reactor operation by recipe would scarcely be attractive to researchers. Such a "black box" would not be a welcome addition to a research laboratory. Moreover, such a procedure would greatly limit the flexibility of reactor use.

With this intent in mind—making available for research use an important tool with a minimum of security strings—the first major declassification action was undertaken in 1950. It was a cautious but significant step in opening up devices that until that time had been concealed from non-Q-cleared view. There were limitations. The information declassified was restricted to that concerning the design and operation of low-powered units, that is, ones with only tens of kilowatts of heat generated. Moreover, because of the inherent closer relationship between highly enriched, undiluted units and the weapons business and because they have distinct advantages in most research applications, only thermal reactors were involved. Further, since it appeared unlikely that reactor fuels would be manufactured in university or off-project facilities, the declassification was confined to fuel geometry and did not include data on fabrication or techniques of manufacture of critical reactor components.

Even with these limitations the 1950 declassification was substantial. All information necessary to the design and operation of the first three Chicago reactors as well as the Los Alamos water boilers was published. At the same time basic nuclear data for uranium and its isotopes were released, that is, those data needed in the design of the completely declassified reactors. This latter action was accomplished in two separate steps with a large part of the nuclear data being released in 1951.

Since the 1950–51 declassification of low-power research reactors we have released further information on other related units. Thus the "swimming pool" reactor, the Knolls thermal test reactor, and the North American homogeneous enriched-uranium, graphite-moderated reactor have all been described with reasonable completeness in the open literature.

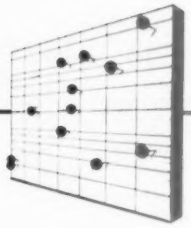
In addition we have tried to publish, beginning in 1950, information on other reactors of interest in research activities. Thus the X-10 reactor has been essentially all declassified. Only fuel element details and a few odds and ends remain classified at Brookhaven. The radiation field of the Materials Testing Reactor has been fully described in the open literature. Certain limited basic data concerning the Experimental Breeder Reactor have been published. These reactors are of such high power level that it is unlikely that universities will wish to build such facilities in the near future. Declassification of information on these higher power units has been based on the desirability of encouraging broader participation in the Commission's research activities. In addition, knowledge of such data is a prerequisite to the healthy growth of the national nuclear energy industry.

There are a number of technical activities associated with reactor development which can be conducted separately from reactor building itself. One of these, the technology of liquid metal use as reactor coolants, has been reported rather fully in the open literature. This appears to be essential to the long-term development of the necessary engineering skills and understanding. Concentration of reactor engineering skills in a few hands is risky and might mean that we would be unable to accomplish any rapid expansion in our reactor program should such expansion ever become urgent.

One field related to reactor development and of substantial interest to basic research is that of radiation damage. We have undoubtedly been too conservative in our declassification of radiation effects data. This should not be of any concern to research reactor groups since all information pertinent to the levels of exposure in all proposed university reactors has been released. Only data on radiation effects on reactor materials for high exposures, say 10^{20} epithermal neutrons per square centimeter and higher, are we reluctant to declassify. For substances of pure research interest, such as, gold-copper alloys, single crystals, etc., even high exposure data are declassified.

All in all, I believe it is true that those interested in the design and operation of research reactors for university use will find ample information in the open literature for the research staff. As far as the reactor designers are concerned, I believe they should be cleared for access to other reactor data not yet declassified. This appears essential for a thorough understanding of such considerations as alternate designs, behavior under unusual conditions, etc. In addition there is a psychological factor involved: one is more confident in a reactor design knowing that the designers were not arbitrarily limited by declassification rules in their access to necessary technical information.

I should like to offer encouragement to those planning a project for the construction and operation of a research reactor. The security and classification problems are not as great as is believed. The reactor at Raleigh is a testimonial to the fact that unclassified operation of a reactor on a university campus is possible.



Safety Problems

By C. ROGERS McCULLOUGH
Chairman, AEC Advisory Committee on Reactor Safeguards
(Monsanto Chemical Company, St. Louis, Mo.)

THERE ARE TWO MAIN HAZARD problems with reactors. The first is the possibility that the nuclear reaction will get out of control, the power will rise to a very high level in an exceedingly short time, and parts of the reactor will melt or vaporize. As far as we know, there is little chance of any existing or proposed reactor causing blast damage as a result of a run-away nuclear reaction. Certainly, no university campus should have a reactor in which there is any real possibility of such an event.

The second problem is that reactors store up fission products, which are exceedingly poisonous substances. If these extremely toxic materials are permitted to get out of the reactor enclosure, even in minute amounts, persons and other forms of life will be seriously damaged. The toxic effect of fission products is three million to two billion times as great as the most potent industrial poison, chlorine. Even compared to cancer formers, benzidine and naphthylamine, they are 2-20 million times as deadly.

It turns out that reactors of the type that are of most interest for research purposes, when properly designed and operated are quite stable and controllable from a nuclear point-of-view. The possible hazard turns out to be the possibility of chemical reactions, for example, the possible reaction of aluminum with water. If such reaction should occur to any extent, the possible heat release, and even explosion might be sufficiently great to rupture the shield and cause the release of fission products. Whether or not such reactions can in fact take place, how probable they are, and what the consequences might be are matters of considerable controversy. Gradually we are accumulating data on this subject and hopefully we can arrive at some reasonable appreciation of this problem and find means of designing and operating so that this is not a hazard. In this connection the work carried out by W. H. Zinn of Argonne National Laboratory last summer at the Idaho National Reactor Testing Station is a very great contribution to an understanding of the problem.

One must not lose sight of the fact that the amount of fission products is directly proportional to the integrated heat power of the reactor between fuel unit changes. Therefore, the lower the power that one can operate a reactor the smaller the amount of fission products. Ideally, one would like a reactor in which the fission products are continuously removed. However, this may not be practical or convenient especially for university reactors. The hazard of a reactor can be reduced also by so designing and operating it that it has a minimum of excess reactivity, it is an inherently stable machine from a nuclear point-of-view, it has a low probability of chemical reaction and is in an enclosure which practically guarantees that no fission products will escape. Without being dogmatic it would seem that at this stage of the art of reactor technology that reactors, even in universities, should be in charge of an operating group that is thoroughly trained in the operation of these machines. The operating procedure should be carefully worked out and rigidly adhered to and *even minor deviations should not be tolerated* without review by more than one thoroughly competent person.

In working with reactors we are dealing with hazardous and expensive machines that can react very quickly to produce most unpleasant conditions. There are possibilities of serious losses and delays from reactor accidents but the Safeguards Committee believes that by proper design and operation these can be minimized. The Committee plans to do what it can to advance reactors for research without being reckless or supercautious.

How the Safeguards Committee Operates

The Committee is asking that all proposals be brought to its attention in a preliminary way as soon as they are sufficiently definite that the probable hazards and problems can be foreseen. At that time an attempt is made to list the questions which require answering and the possible problems which need solving before the Committee can make a valid judgment of the hazards involved. Finally, a formal "Hazards Summary Report" is submitted to the Committee for consideration and action. Presumably, favorable action on the "Hazards Summary Report" is required before the reactor starts operation. By proceeding in this manner at the time when the final evaluation must be made, there should be a satisfactory solution of all but minor problems and the reactor can be completed and go into operation with the assurance of reasonable risk on the part of the owners and operators and AEC.

Air Force Interest

There are seven reasons why Wright-Patterson Air Force Base is interested in building a swimming pool reactor:

1. **To study radiation damage on materials used in nuclear propulsion systems**
2. **To develop materials**
3. **To study nuclear properties of materials**
4. **To learn about design of shields for aircraft**
5. **To study reactor instrumentation and control**
6. **To carry out radioisotope applications including activation analysis**
7. **To give on-the-job training**

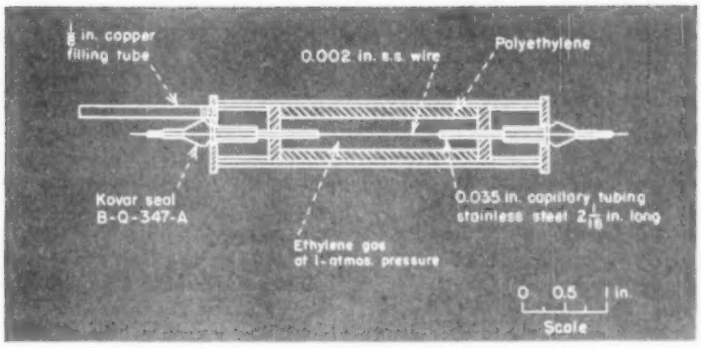

1/8 in. copper filling tube
0.002 in. s.s. wire
Polyethylene
Kovar seal B-Q-347-A
0.035 in. capillary tubing stainless steel 2 1/16 in. long
Ethylene gas of 1-atmos. pressure
0 0.5 1 in.
Scale

FIG. 1. Fast-neutron counter

Fast-Neutron Dosimetry in a Small Tissue-Equivalent Phantom

Results directly applicable in biological studies are presented for neutron attenuation and dose build-up in tissue. Dosimetry of a phantom irradiated by Po-B and Po-Be sources was determined with an ethylene-filled proportional counter

By W. A. MILLS and G. S. HURST
Health Physics Division
Oak Ridge National Laboratory, Oak Ridge, Tennessee

INCREASED USE of fast-neutron sources in the physical laboratory has shown the need for information on neutron build-up and attenuation in tissue. Ability to express the dose a man actually receives in terms of measurements made by a small dosimeter placed in air is of considerable importance.

Due to the lack of suitable sources and fast-neutron dosimeters, such studies have not been as exhaustive as in the case of X-rays and gamma rays (*1–3*). It is well known that when a tissue medium is irradiated with X-rays or γ-rays, the dose (energy dissipated in a gram of tissue) just below the surface of the tissue is greater than the dose that would be measured at this same point if the tissue were replaced by air. This increase in dose is referred to as build-up.

Depth-dose curves for neutrons of various energies have been calculated by Snyder and Neufeld (*4*) by means of the Monte Carlo method. In these calculations, a 30-cm slab of tissue was used as a model for the human body with a normally directed beam of 1 n/cm^2/sec entering the slab.

Barr (*5*), to verify the results of Snyder and Neufeld, experimentally determined depth-dose curves for a 30-cm slab of tissue-equivalent material. A polonium-boron (Po-B) fast-neutron source was placed at distances from 6 to 197 cm from the center of a cylindrical tank of 2-meter diameter.

The object of the work reported herein was to determine the dose delivered to a small phantom (15.2 $\times$ 15.2 $\times$ 28 cm), comparable in size to a small animal or to a human head, by fast neutrons from two sources with different energy spectra. The results can

then be compared to those of Barr to see if there are appreciable differences in the depth-dose curves due to the difference in phantom sizes.

Measurement Method

The phantom was made by filling an aluminum container with water, sucrose, and urea in such proportions that the solution contained the per cent-by-weight figures in the table, where a comparison with average wet tissue (*6*) is made.

Detecting equipment. The detector used was a proportional counter (*7*) using ethylene gas surrounded by a polyethylene wall, thus conforming to the Bragg-Gray principle (*8*). Counter construction is shown in Fig. 1.

A pulse integrator (*9*) was used to record the pulses received from the counter. This instrument, consisting of a power supply, a pulse sorter and two scalers, gives a counting rate that is proportional to the dose rate in terms of roentgens-equivalent-physical, or reps, per unit time. (The rep is defined as that amount of radiation absorbed to the extent of 93 ergs per gram of tissue.) Figure 2 is a block diagram of the experimental apparatus.

Since only the dose due to fast neutrons was of interest in these measurements, the counter high voltage was adjusted so that gamma rays formed pulses less than the voltage of the first discriminator of the pulse integrator. This was done by means of a cobalt-60 source of known strength placed at such a position as to give approximately 2 r/hr on the center of the counter. This check was repeated periodically to assure the same gamma sensitivity throughout the experiment.

Irradiation arrangement. Two sources of fast neutrons were used in the measurements, Po-B, with the maximum number of neutrons at 2.5 Mev, and Po-Be, with an average energy of 4.6 Mev (*10*).

It was necessary to determine the effect of the $\frac{1}{4}$-in.-thick aluminum shell used as the solution container. Measurements taken on the inside of the shell, with the solution removed, were compared with measurements taken in air. No significant difference was found.

Figure 3 shows the irradiation arrangement used for the dose-rate measurements. The source was placed at distances of 25, 50, and 100 cm from the center of the phantom. In the phantom, with the center as the origin, the counter was moved on polar-coordinate axes. Measurements of dose rates were taken at radii of 0, 3, 5.9, and 8.2 cm and at 45-deg intervals. Measurements in air were also taken at the same positions.

Also shown in Fig. 3 is the paraffin cone used to shadow the counter against the primary beam of neutrons. Measurements with and without the cone gave an indication of the scattering into the counter from the laboratory walls, floor, etc. Data were obtained for each of the sources for both the scattering in air and the scattering in the phantom at 50 and 100 cm, and an approximation was made of the scattering at the 25-cm distance. From this data, scattering corrections were then made for the dose rates recorded without the paraffin cone present.

An empirical equation was formulated for the decrease in dose rate along the center line in the phantom, or the phantom axis, for each source. This empirical equation can be expressed as

$$I = \frac{I_0}{(D + X)^2} B e^{-X/L} \qquad (1)$$

where I = dose rate (rep/sec) in the phantom at a depth of X from phantom's front surface, I_0 = dose rate at 1 cm from source in air, D = distance from source to phantom's front surface, B = build-up factor for source, and L = the relaxation length for a particular source in the phantom.

Results. From the data obtained along the phantom axis, the two constants B and L were determined. In the case of the Po-B source, B = 1.20 and L = 10.0 cm. For the Po-Be source, B = 1.33 and L = 11.3 cm.

The dose rate at 1 cm, I_0, can be

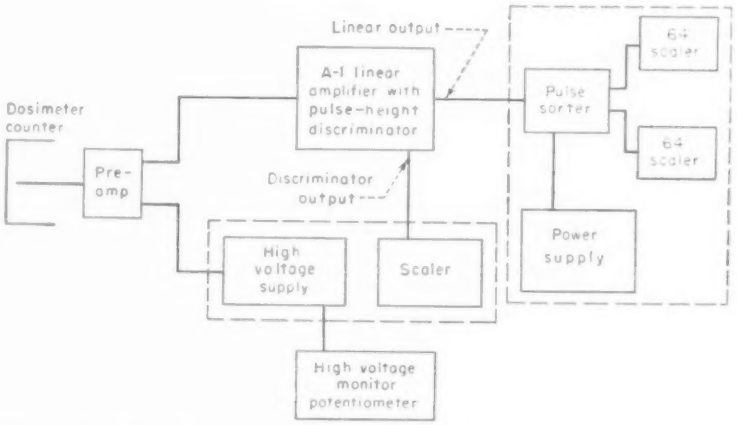


FIG. 2. Experimental apparatus; counter output recorded by pulse integrator at right

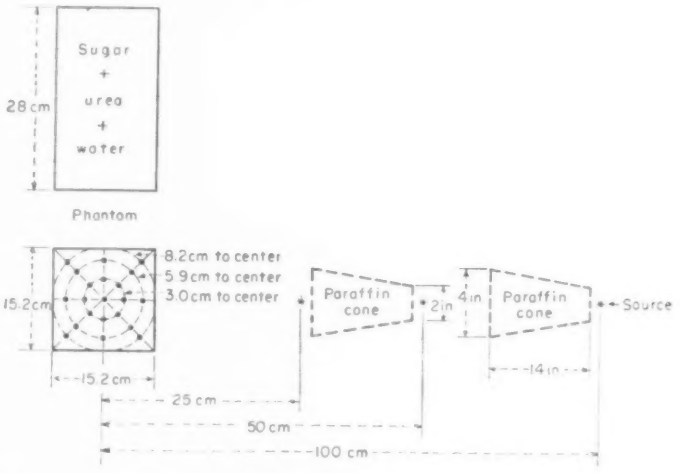


FIG. 3. Irradiation arrangement; cross section of phantom shows positions of counter

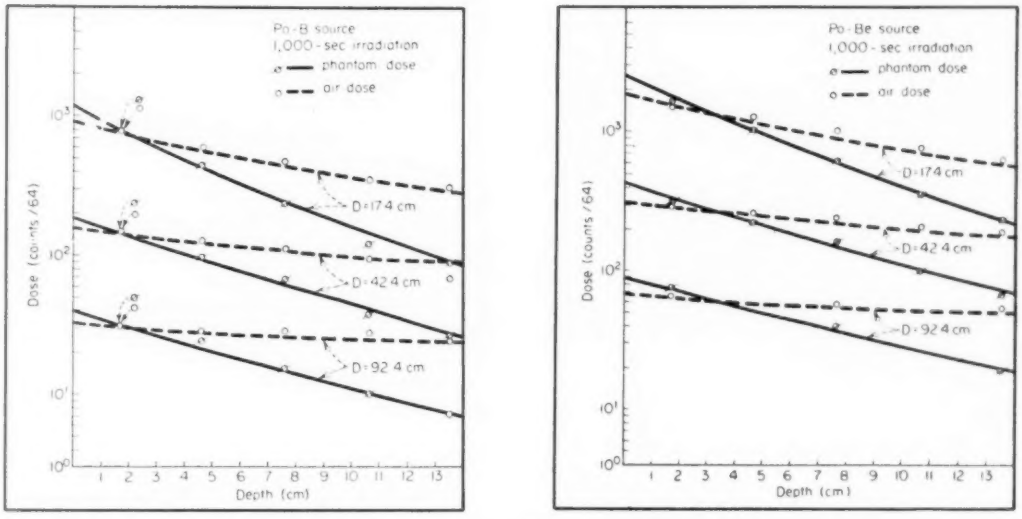


FIG. 4. Depth-dose curves for Po-B and Po-Be sources; counting rates are proportional to rep/sec

determined from the neutron flux at 1 cm, in terms of neutrons/cm²/sec, and the energy dissipated in tissue. The energy dissipated has been measured as 4.45×10^{-9} rep/n/cm² for a Po-Be source and 3.54×10^{-9} rep/n/cm² for a Po-B source (*11*). The product of the flux (neutrons/cm²/sec) at 1 cm and the dose per neutron/cm² gives a dose rate in terms of rep/sec.

The accuracy of the fit of Eq. 1 can be judged by the curves given in Fig. 4, where I is plotted against X; I is in terms of counting rate. The dashed curves show the air dose rate as a plot of the inverse square law

$$I = \frac{I_0}{(D+X)^2} e^{-\mu(D+X)} \qquad (2)$$

neglecting the very small effect of air attenuation ($e^{-\mu(D+X)}$, where μ = linear absorption coefficient). The points shown in the figures are the experimental values obtained in the measurements. Although all counting rates were of such magnitude as to give a statistical error of 5%, slight changes in geometry of the system might make the over-all error as large as 10% in some cases.

Conclusion

Barr, using the larger phantom, found that the build-up at the surface was 1.5 and that the relaxation length was 7.5 cm, while values reported here are a build-up of 1.20 and a relaxation length of 10.0 cm. In both cases, the phantom mixture was the same and a Po-B source was used in the irradiation. The difference in the results can be attributed to the phantom size.

The results of this work, as well as the results of Barr and Snyder and Neufeld, can be used as presented for biological and medical studies in applicable circumstances. However, the use of the results for health physics problems of "survey-monitoring" requires a word of clarification.

Suppose it is desired to measure the "dose" of neutrons in an area where the working time is to be established. The procedure that should be followed is, first, calibrate a neutron dosimeter in air, either by using a "first collision" calculation to determine the incident dose from a known source or by measuring the dose independently and in absolute units with a "standard" neutron dosimeter. When the instrument is then placed at the point in question, it will measure the dose rate at that point and *under those conditions.*

If a man is placed at this point, his surface dose rate will increase, due to build-up, by an amount depending on the neutron energy. Adjustment of this factor should be made either by measuring the dose with a phantom present or by using the results of phantom measurements, such as the ones reported, in lowering the working time. In the interest of consistency, the build-up factor should not be applied to the instrument calibration, in order that the instrument will always measure the correct dose at the site where it is placed.

* * *

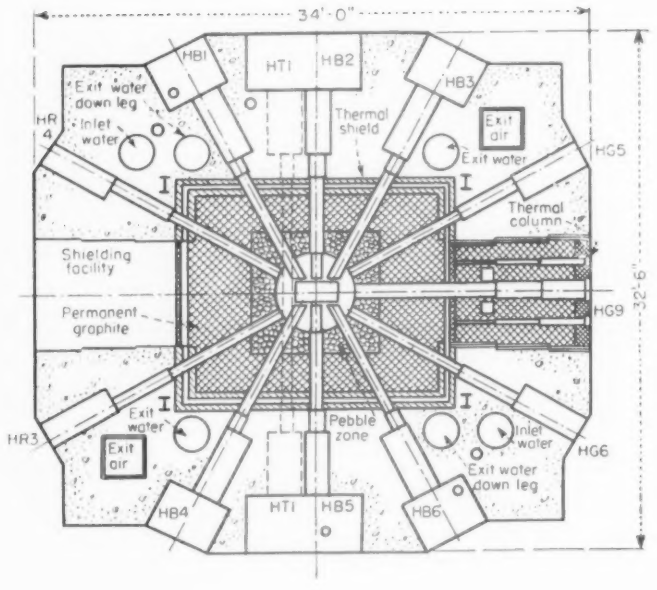
The authors are grateful for the many helpful suggestions and the valuable assistance given by T. A. Barr and J. A. Harter, of the Oak Ridge National Laboratory, Health Physics Division. Oak Ridge National Laboratory is operated for Atomic Energy Commission by the Carbide and Carbon Chemicals Company.

Comparison between Phantom Tissue and Average Wet Tissue

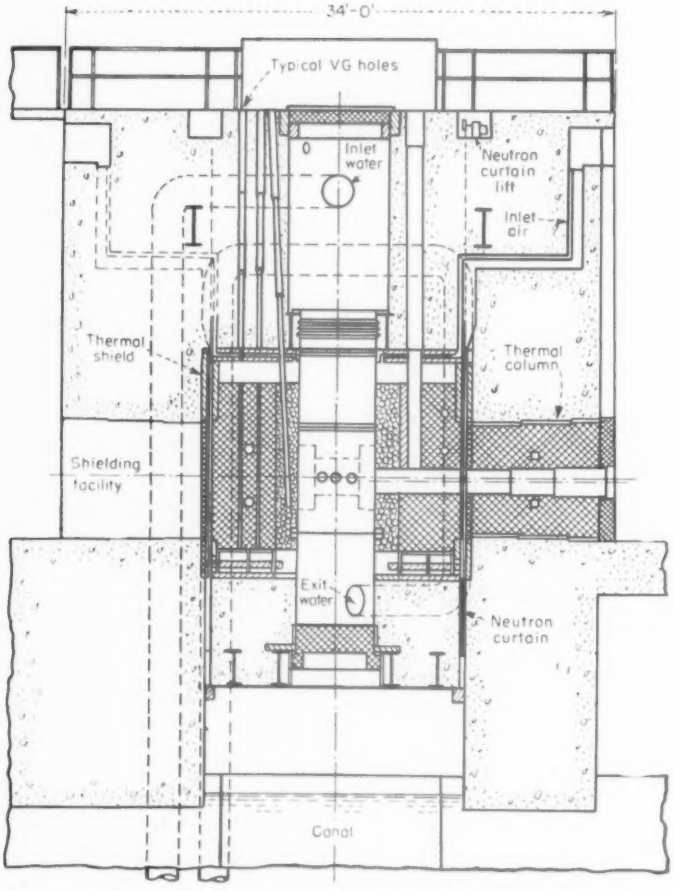
	Per cent by weight	
Element	*Phantom tissue*	*Average wet tissue*
Oxygen	74.91	74
Carbon	11.54	12
Hydrogen	9.73	10
Nitrogen	3.84	4

BIBLIOGRAPHY

1. W. V. Mayneord, *Brit. J. Radiol.* **13,** 235 (1940)
2. W. V. Mayneord, A. J. Cipriani, *Can. J. Research* **25A,** 303 (1947)
3. L. F. Lamerton, *Brit. J. Radiol.* **13,** 136 (1940)
4. W. S. Snyder, J. Neufeld, Maximum permissible neutron flux for fast and thermal neutrons, unpublished, ORNL
5. T. A. Barr, Fast neutron dosimetry in a 30 cm tissue equivalent phantom, unpublished, ORNL
6. D. E. Lea, "Actions of Radiations on Living Cells" (Macmillan Co., N. Y., 1947)
7. G. S. Hurst, R. H. Ritchie, *Radiology* **60,** 864 (1953)
8. L. H. Gray, *Proc. Cambridge Phil. Soc.* **40,** 72 (1944)
9. F. M. Glass, G. S. Hurst, *Rev. Sci. Instr.* **23,** 67 (1952)
10. I. H. Perlman, H. T. Richards, L. Speck, MDDC-39 (1946)
11. G. S. Hurst, An absolute tissue dosimeter for fast neutrons, submitted to *Brit. J. Radiol.*



Irradiation facilities, control and cooling systems, and general design of the MTR are described in this article. Located at the National Reactor Testing Station, it provides radiation intensities close to those expected in future power reactors



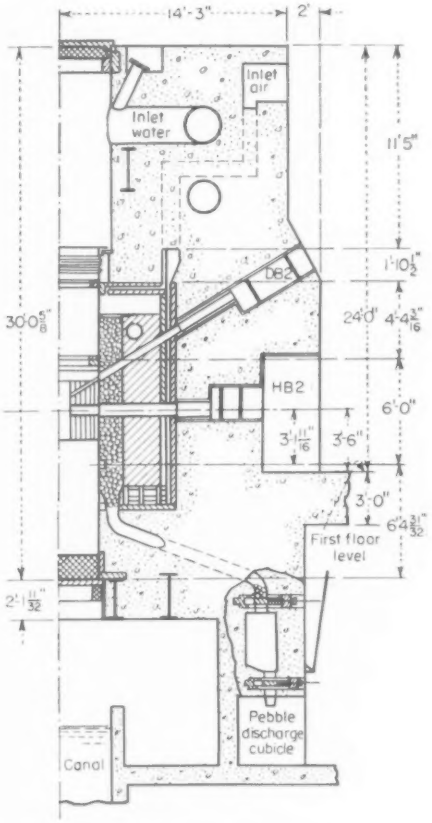


FIG. 1. Orthogonal projection of the Materials Testing Reactor showing center-plane plan and cutaways of core and tank

The Materials Testing Reactor

By JOHN R. HUFFMAN
Atomic Energy Division
Phillips Petroleum Company
Idaho Falls, Idaho

THE HIGHEST NEUTRON FLUX of any reactor now in existence is available in the Materials Testing Reactor.

Designed primarily for testing materials and components in high-intensity radiation, it has about 100 experimental holes. Several holes can be used to irradiate reactor components, such as fuel assemblies, under simulated operating conditions of temperature, pressure, and particular coolant.

This article describes the Materials Testing Reactor design—with particular emphasis on its experimental facilities.

THE REACTOR

The MTR operates on thermal neutrons and uses enriched uranium as fuel, ordinary water as both moderator and coolant, and beryllium as reflector. It operates at 30,000 kw.

Because of its high specific power (heat developed/unit weight of fuel), average neutron fluxes of 2×10^{14} thermal neutrons/cm²/sec and 1×10^{14} fast neutrons/cm²/sec are available. Peak thermal neutron fluxes of 5×10^{14} n/cm²/sec exist in certain reflector positions.

The reactor has a heterogeneous lattice using enriched uranium. Fuel elements are arranged to allow water to flow between them to serve as both coolant and moderator. The active core can be located as desired within the lattice, which is 40×70 cm in cross section and 60 cm high. The bottom of each fuel element fits into a socket in a grid base; another grid fits over the tops of the elements to space them at the top (Figs. 1, 2).

Surrounding the small, enriched lattice is a 3-ft-high primary reflector consisting of beryllium metal. The reflector is perforated vertically with $^3/_{16}$-in.-diameter holes through which water passes to remove heat. Materials can be inserted in the beryllium assemblies to make experimental use of leakage neutrons.

The whole assembly of lattice and reflector is mounted in a tank system that also contains the control rods, their bearings, and the coolant-moderator water. The section of the tank around the lattice is made of aluminum 1 in. thick and has an inner diameter of $54^1/_2$ in. It is extended by stainless steel sections both above and below the active portion of the reactor, forming a 30-ft-deep "well" that is always kept full of water. Water enters the well about 15 ft above the lattice and leaves at the sides of the well about 5 ft below the lattice.

The reactor tank is closed top and bottom by heavy lead-filled (11-in.-layer of shot) steel plugs. The driving mechanisms for the control rods are mounted on the top plug. This plug can be removed (when the reactor is shut down) to load or unload fuel elements or reflector sections.

Unloading of radioactive items is accomplished through 20 ft of water (dose < 0.1 r/8 hr) by using hand grappling tools. The objects are lifted just above the beryllium reflector and moved to a position directly over a hole through the reflector that is filled with a beryllium plug during reactor operation. Beneath this hole is a water-filled discharge tube leading to a receiving tube in an 18-ft-deep canal.

The aluminum section of the tank can be replaced without dismantling major portions of the graphite or shielding. Components within the highly-active zone in the reactor are made of materials having short-lived induced radioactivities. Thus, another type of reactor (of identical external dimensions) can be inserted in the hole left by the removal of the present reactor tank.

To provide additional space having thermal neutron fluxes above 10^{13} n/cm²/sec, a secondary reflector of graphite is placed outside the reactor tank. The possibility of dimensional changes due to radiation, oxidation, and temperature dictated dividing the graphite reflector into two zones: a pebble zone extending a minimum of 50 cm from the reactor tank wall, and a permanent graphite zone 12×14 ft by $9^1/_3$ ft high.

The pebble zone, $7^1/_3$ ft square by 9 ft high, is filled with 700,000 graphite 1-in.-diameter pebbles. The pebbles are free to expand upward without exerting undue stress on the tank wall or the permanent graphite. If the pebbles are damaged, they can be removed through two discharge chutes and replaced.

The permanent reflector is composed largely of 4×4 in. rectangular graphite bars stacked to a height of $9^1/_3$ ft. This graphite structure is penetrated by vertical holes that can be used for experimental purposes or for cooling. The sides are penetrated by holes designed especially for experimental uses.

Uses and Importance

Power reactors of the future will have high specific powers (watts/gm of fuel) so as to conserve uranium and improve breeding. The MTR is used to test materials and components for these high-flux reactors. Also, the MTR is useful for experimental nuclear physics studies and for radioisotope production.

Surrounding the graphite is a thermal shield consisting of two 4-in.-layers of steel that absorb most of the escaping neutrons and residual radiation energy from the reactor. The layers are spaced 4 in. apart to provide an air passage for cooling. The thermal shield is approximately 16 × 14 ft by $12\frac{1}{2}$ ft high.

Finally, a barytes concrete (gravel is ~ 93% $BaSO_4$) shield about 9 ft thick reduces the radiation level to a low instrument background. This level is lower than human tolerance by a factor of 10. The outer dimensions of the structure form roughly a 32-ft cube.

COOLING

When the total reactor is producing 30,000 kw of heat energy, the heat actually developed in the various parts is —28,800 kw in the fuel elements, 1,200 kw in the beryllium, 500 kw in the graphite, 48 kw in the thermal shield, and about 2 kw in the concrete.

The reactor core and the beryllium reflector are cooled by demineralized water flowing at a rate of 20,000 gal/min. The water is fed from a 170-ft-high head tank, enters the top of the reactor tank at 100° F and leaves below the core at 111° F. It goes to a vacuum spray evaporator system for cooling and is then elevated to the head tank by 10,000-gal/min centrifugal pumps. Purge water flows to a retention basin for radioactive decay and then passes to the surrounding terrain. A secondary circulating stream of water from a cooling tower is used in the condensors of the spray evaporators.

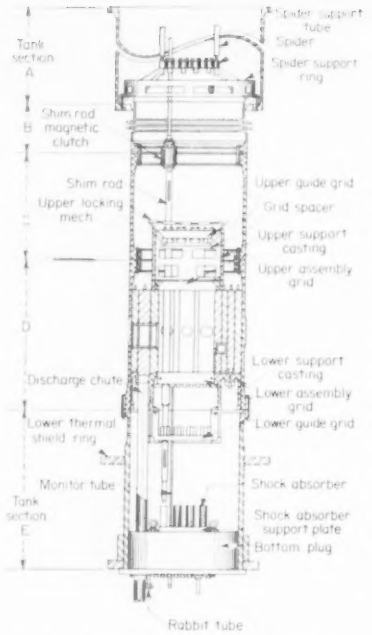


FIG. 2. Cutaway of reactor tank assembly

The graphite reflector and thermal shield are cooled by air flowing at a rate of 1,700 lb/min. Large blowers in a fan house create a suction within the reactor structure so that the air is taken from the reactor building. It is discharged to the atmosphere 250 ft above ground level through a stack.

Figure 3 shows the heating caused by gamma rays. Estimates of the total heat developed in any material must also include fission heat and neutron-capture heat.

CONTROL SYSTEM

The control system functions as a closed loop. The reactor is affected by control rods, auxiliary facilities, and disturbances. It, in turn, affects instruments that produce information transmitted to the operator and to the control system. They also receive information from selsyns and other indicators of rod position or rod motion. On the basis of the information received, taken together with the operator's actions, the control system transmits appropriate control signals to the control-rod motors or magnets. These cause rod motions, which in turn affect the reactor.

The reactor is controlled manually by the operator and automatically from instrument signals in such a way that the operator and instruments serve as mutual checks on each other.

The control elements serve two purposes—the safety function and the regulator function.

Some of the safety and protective elements warn the operator that action is necessary, others automatically limit the speed of control-rod withdrawal, reduce power level, or shut the reactor down. The latter three functions are accomplished, respectively, by "pe-

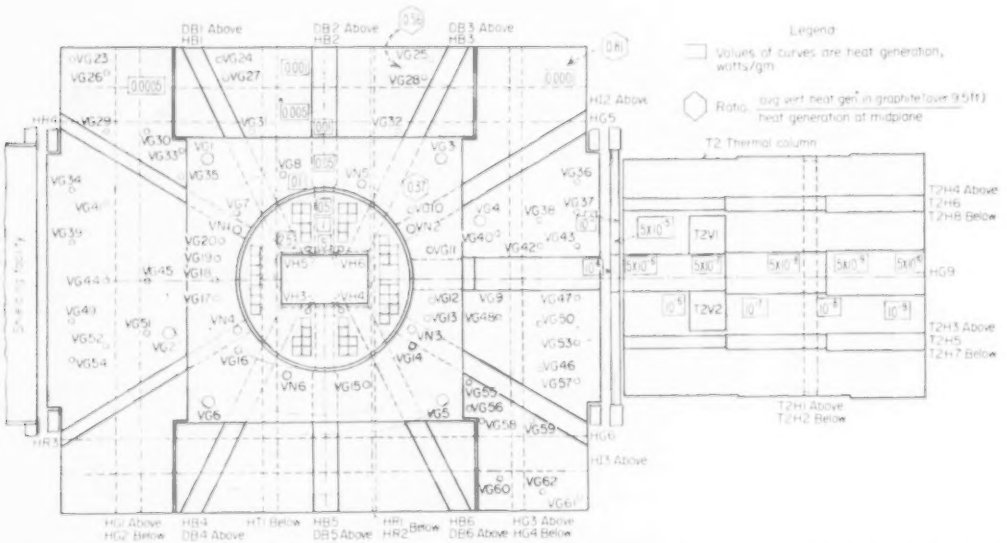


FIG. 3. Gamma-heat generation pattern at reactor midplane for 30-Mw operation. Curves are shaded area boundaries

TABLE 1—Radiation Detectors on the MTR*

Instruments	*Use*
Parallel-circular-plate ion chamber	Safety and servo signals
Compensated ion chamber	Log N (neutron flux), period, galvanometer signals
Fission chamber (12-ft travel)	Counting-rate signal
Air-wall ion chamber	Activity of N^{16} in water
Water-monitor ion chamber	Water-sample monitor
Boron thermopiles	Neutron flux in graphite

* For description of instruments, see NU, June '53, p. 35.

riod" control, a motorized rheostat, and release of magnetic clutches on the shim safety rods.

Period control is based on an electronic device that measures the time derivative of the logarithm of the neutron flux. Reduction of the power level to about 1% of the normal operating level is valuable in emergencies in which a more drastic scram might not be justified. Reduction is brought about by signals from instruments indicating neutron flux and from monitors on cooling-water activity, cooling-air activity, experimental facilities, instrument elements, etc. Scram (complete shutdown) signals come from instruments indicating the neutron-flux level and from a few critical monitors such as those for cooling-water flow. Interlocks serve as step-by-step checks on the operator to prevent serious mistakes.

Regulating requirements are met by a servomechanism that controls the motion of the regulating rod whose position, in turn, dictates movement of shim rods. The regulating rod itself controls about 0.5% reactivity (less than the effect of delayed neutrons) for fine regulation. This small effectiveness was chosen so that a servomechanism malfunction cannot make the reactor prompt critical.

Regulating Rods

Although one regulating rod is sufficient for control of the reactor, a stand-by is provided. Four locations in the beryllium reflector are available for these rods. Each rod is 1.5 in. in diameter and contains a 23-in.-long center section with cadmium sandwiched in stainless-steel tubing. Guides are provided in the upper and lower grid supports. Total weight of the rod and connecting shaft is approximately 55 lb.

The rod is driven by a low-inertia, high-starting-torque d-c electric motor through a pinion and rack on the rod. The motor is driven by an amplidyne.

Shim, Safety Rods

Eight spaces are provided in the reactor lattice for shim safety rods; all need not be used. The shim rods are driven mechanically by a worm drive and reversible 3-phase induction motors remotely controlled by reversing contactors that are electrically and mechanically interlocked. The drives have upper and lower limit switches. The advantage of the induction motor is that no accident can make it run in excess of synchronous speed; therefore, the danger of overspeed withdrawal of the shim safety rod is eliminated. No brakes are required during reversal because the drive mechanism utilizes the self-locking features of a worm-and-acme screw.

To provide the scram or safety feature for the shim safety rods, an electromagnetic (bipolar or horseshoe) coupling is used between the vertical lifting shaft and the rods. The magnet is wound with 3,500 turns of fine wire so that a 100-ma current will hold a load of 500 lb. It releases a 600-lb load held at 140 ma in 15 msec or less. The current is supplied by a vacuum tube that releases the magnet when the grid becomes less positive than usual. The time lag (< 0.02 sec) in the release of the shim rod by the magnetic coupling is short enough that the chain reaction will be stopped safely even if the operator inadvertently is withdrawing the shim rods at their maximum rate with the reactor superprompt critical.

A period meter gives a scram signal (de-energizing the magnetic clutches and letting the rods drop) if the period is less than 1 sec. The meter causes the shim rods to be inserted by their motors when the period is less than 5 sec.

The safety scram circuits give an alarm when they are not in perfect operating condition. The alarms indicate not only failure and incipient failure, but also tell where it occurs or is likely to occur (e.g., short circuit in the cable, weak tube, lack of power).

As the shim safety rods are raised, they bring fuel sections into the lattice. Each rod has a cadmium sheet in the upper section; this section resides in the lattice when the rod rests in its lower shock absorber. The rods are extended top and bottom by square, hollow stainless steel sections. The top of the rod forms the armature for the magnetic clutch, and the bottom forms a tapered plunger. On emergency release of the rod, the energy resulting from the fall is transferred to water forced out of a dashpot by the

Xenon Poisoning

The operator must quickly get the reactor going again after accidental shutdown from steady, high-power operation or it will not start for about two days.

The difficulty is caused by the buildup of the high cross section Xe^{135} after shutdown (during operation, Xe^{135} does not buildup in concentrations sufficient to cause a reactivity loss of more than 4% Δk k because it is destroyed by absorption of neutrons soon after the atoms are formed). The Xe^{135} (9.4 hr half-life) is a decay product of the fission product I^{135} (6.6 hr half-life). A reactivity loss of 9% builds up within the first hour after shutdown, 16% within 2 hr, and the maximum loss occurs after 10 hr. After 48 hr the reactivity is only a few per cent less than during steady operation at 30,000 kw. After 63 hr the reactivity is equal to that during sustained operation.

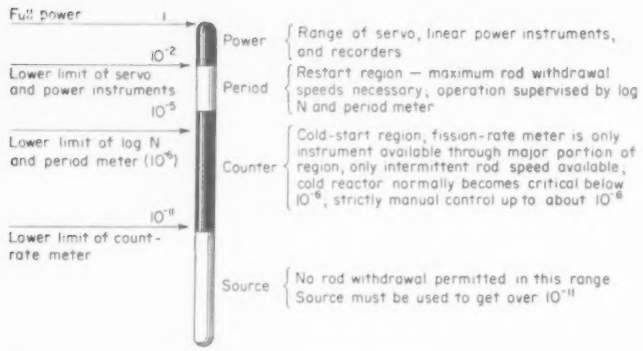

Full power
10^{-2}
Lower limit of servo and power instruments
10^{-5}
Lower limit of log N and period meter (10^{-6})
10^{-11}
Lower limit of count-rate meter
Power
Range of servo, linear power instruments, and recorders
Period
Restart region — maximum rod withdrawal speeds necessary; operation supervised by log N and period meter
Counter
Cold-start region; fission-rate meter is only instrument available through major portion of region; only intermittent rod speed available; cold reactor normally becomes critical below 10^{-6}, strictly manual control up to about 10^{-8}
Source
No rod withdrawal permitted in this range
Source must be used to get over 10^{-11}

FIG. 4. Instruments used in various power ranges

tapered plunger on the rod.

Graphite-faced guides with roller bearings are mounted about 3 ft above and below the active lattice. They are in guide support grids and are lubricated by the cooling water. The motors, drive mechanisms, position indicators, limit switches, etc., associated with both the regulating and the shim rods are located on top of the reactor tank plug. The dashpots are in the bottom of the reactor tank.

Instrumentation

Neutron-flux signals for operating the control circuits come from 10 to 14 instruments located in the 10 instrument holes provided in the reactor structure.

Three groups of instruments furnish information to the operator and to the control system: reactor instruments measuring neutron flux or power level, rod-position and -motion indicators, and instruments for the auxiliary facilities.

Reactor instruments include radiation instruments (listed in Table 1) measuring neutron level in the reactor and radioactivity in the water; instruments measuring exit-water temperature distribution across the active lattice, temperatures in the thermal and biological shields; and Pitot tubes measuring distribution of water flow across the bottom (exit) of the fuel elements. Figure 4 shows the relation between power (or neutron) level and the choice of instrument and control action in four definite ranges.

Numerous thermometric devices are used for observing temperatures in other parts of the reactor. Thermocouples in the inlet and outlet water lines measure temperature rise, which is multiplied by the total water flow (as measured by a Venturi flowmeter) to give power absorbed from the reactor.

Irregularities in cooling-air pressure and flow and in radioactivity in the air stack are reported to the operator by alarms. Air-flow failure causes a mild automatic safety action (slow setback).

To make reactor operation free from effects of transient disturbances or outages on the purchased-power lines, electrical power for the control system is obtained from a special supply. It consists of two alternators operated from storage batteries charged by two converters on the power supply. In normal operation, one alternator supplies instrument-bus voltage, and the other supplies relay-bus voltage.

TABLE 2—Summary of MTR Experimental Facilities

Facility	*Size*	*Approach*	*Estimated Maximum Thermal Neutron Flux*
HB1–3	6-in. ID in Be	Horiz. to core	4.5×10^{14}
HB4–6	6-in. ID in Be	Horiz. to core	2.5×10^{14}
HG1, 2	8-in. ID	N-S horiz. through graphite	1×10^{12}
HG3, 4	4-in. ID	N-S horiz. through graphite	1×10^{12}
HG5, 6	6-in. ID	Horiz. to tank wall	4×10^{13}
HG9	10×16 in.	Horiz. to tank wall	4×10^{13}
HT1	$4\frac{7}{8} \times 4\frac{7}{8}$ in.	Horiz. through tank	1.2×10^{14}
HI2, 3	$10\frac{3}{4}$-in. ID	E-W horiz. through graphite	1×10^{12}
T2H1, 2	4×4 in.	N-S horiz. across T2	2×10^{9}
T2	6×6 ft	Horiz. to Pb window	1×10^{11}
T2H3–8	4×4 in.	Horiz. in T2	1×10^{11}
T2V1, 2	12×12 in.	Vert. reactor top to T2	2×10^{10}
HR1, 2	1-in. ID	Horiz. through tank	1.2×10^{14}
HR3, 4	4-in. ID	Horiz. to tank	4×10^{13}
DB1–3	6-in. ID	Inclined down to tank wall	2×10^{13}
DB4–6	6-in. ID	Inclined down to tank wall	5×10^{12}
VG1, 3, 5, 6	4-in. ID	Slant from top to pebbles	6×10^{12}
VG2, 4	4-in. ID	Vert. through graphite	5×10^{12}
VG7, 10–14, 16–20	$2\frac{1}{2}$-in. ID	Slant from top into pebbles	2.5×10^{13}
VG9	10×10 in.	Vert. from top to HG9	8×10^{12}
VG23–26, 29–41, 43, 45–55, 57–62	2-in. ID	Vert. from top into permanent graphite	5×10^{10} to 5×10^{12}
VH1–4	1- & 1.3-in. ID	Vert. from basement, in Beryllium	$2–3 \times 10^{14}$

IRRADIATION FACILITIES

A large and varied assortment of flexible irradiation facilities is available in the MTR. Table 2 summarizes these facilities and gives the estimated maximum neutron fluxes in each. These are the fluxes in the unperturbed condition; they are affected by materials in test equipment inserted either in the facility or in adjacent facilities. They are also affected by the location of the reactor core in the lattice region.

Figure 5 shows the estimated thermal neutron fluxes throughout the reactor structure at the geometric vertical centerline of the lattice. Fluxes

in the reflector positions, the horizontal beam holes, and the shuttle tubes are highest. Since the fast neutron flux falls off very fast in the reflector, experiments must be located in the fuel zone to obtain the highest fast fluxes.

The flux distribution in the vertical direction is roughly a cosine over the height of the reactor and reflector. Because of perturbations due to experiments and because of the position of the control rods during operation, this cosine distribution can become quite distorted. And, since fuel is continually burned up, the neutron fluxes will vary somewhat during operation. Hence, values given are only estimates.

Reflector Positions

Sections of the reflector can be removed from inside the reactor tank and test items irradiated in the vacant positions. Special beryllium or aluminum reflector pieces with proper-size holes to handle the test equipment are used.

Generally, experiments in these positions are of the "pre-post" type, i.e., they are inspected before and after exposure and do not require any interconnections during irradiation. However, a few small tubes for thermocouple leads, electrical leads and very small coolant pipes can be brought out through the tank access holes.

Horizontal, Downbeam Holes

There are 17 main experimental holes. They are accessible at the outer concrete shield face and extend inward to the reactor tank wall or, in some cases, to the reactor lattice through thimbles in the reactor tank (Fig. 1).

Since these holes penetrate to the highest flux in the reactor and provide the largest streams of radiations from the reactor, they are potentially dangerous; their use is difficult and complicated. Each has a special radiation door whose purpose is to minimize danger to personnel in the reactor building during the loading and unloading of shielding plugs in the irradiation holes.

The horizontal beam holes (HB) extend horizontally from the shield face to the active lattice. Holes HB2 and HB5 are 8 in. in diameter to the reactor tank and 6 in. in diameter from there to the active lattice. The other HB holes are 6 in. in diameter throughout their lengths.

The downbeam holes (DB) are extended essentially to the lattice by 2-in.-ID sealed air-filled aluminum cans in the beryllium reflector.

The horizontal through hole (HT1) extends from one shield face to the opposite face. It goes through the reactor tank and is adjacent to one side of the active lattice.

In addition to the main experimental holes, there are six more horizontal through-holes in the graphite. Four of these, HG1 to HG4, are for experimental work; the other two, HI2 and HI3, are for reactor control instruments.

The beam holes are filled with long close-fitting plugs to complete the shield of the reactor. The parts of plugs are made of beryllium where they reside in the beryllium reflector, of graphite in the graphite reflector, iron through the thermal shield and concrete in the biological shield. Because of heat evolved in their beryllium sections, each HB plug has its own water cooling system. For experimental work, a new plug must be designed and built with the test equipment attached to the front-end or em-

Thermal Neutron Flux Highest Outside Core

The MTR's maximum slow neutron flux exists, not in the active portion of the reactor, but in the adjacent reflector. This is due to the high neutron leakage from the MTR's core and because the absorption cross section per unit volume of the beryllium is less than that of the core material. Neutrons thermalized in the reflector live longer than those becoming slow in the core. Extent of rise depends on reactor shape—is greatest for a slab-type of loading (where leakage is greatest) and least for a cylindrical loading. Maximum rise is about twice average core flux.

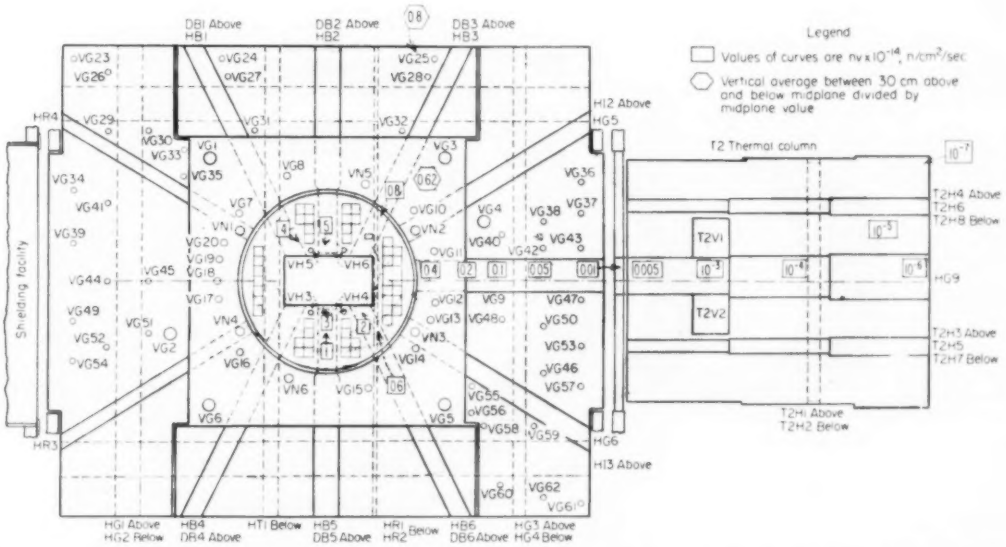


FIG. 5. Thermal neutron flux pattern at reactor midplane for 30-Mw operation. Curves are shaded area boundaries

bedded in the plug and properly cooled.

Since portions of any plug inside the thermal shield become highly radioactive, heavy lead-shielded casks are required for removing them. A 41,000-lb-"universal coffin" is used for the horizontal beam plugs. The front end of the coffin has 10 in. of lead for shielding the beryllium parts of these plugs.

To remove a plug, the coffin is accurately aligned with the hole. The lead door of the coffin is raised, the plug is pulled into the coffin, and the radiation door in the reactor structure and the lead door of the coffin are closed. The plug is transported in the coffin to a plug storage facility outside the building.

Since the radiation doors in the reactor structure do not provide sufficient shielding during reactor operation, the removal of plugs is possible only during shutdowns. There is another reason why loading and unloading equipment or material in these holes or in reflector positions must wait on times when the reactor is normally shut down for fuel replenishment. This is caused by the fact that the buildup of xenon poisoning after shutdown is such that the MTR cannot be started for 70–80 hrs after more than a 15–30 min shutdown. Hence, it becomes impractical to consider shutting down the reactor to remove or replace experiments that require longer times. For these reasons experiments placed in these positions are expected to be in the reactor for long periods—say 20–30 days—unless breakdowns require their removal.

Vertical Holes

The MTR has 71 experimental and instrument holes accessible from the top of the reactor. Some of these penetrate into the pebble zone and some into the permanent graphite; two are also accessible from a room under the reactor. Generally, diameters range from 2 to 4 in. Four of these holes are 6-in. thimbles extending into the exit-water lines, two for measuring exit-water activity and two provide high-gamma-flux facilities. One hole is a 12-in. square penetrating to the inside tip of the HG9 hole coming through the thermal column. Two other 12 × 12-in. holes penetrate vertically downward into the thermal column.

Thermal Column

The thermal column is 6 ft square and 8 ft long. It is outside a 4-in.-thick lead window that reduces the gamma flux entering the column. The outer face is protected by a 10-in.-thick lead shielding door. Six 4 × 4-in. graphite stringers penetrate the thermal column to the inner lead window. A 9 × 15-in. hole, HG9, penetrates the thermal column to the reactor tank wall. Two 4 × 4-in. holes at 90 deg to the column penetrate from the reactor face to the opposite face. In addition, the two 12 × 12-in. vertical holes mentioned previously are available.

At one time, there was a second thermal column in the design. Later, it was converted to a facility for testing shielding materials. Subsequently, this facility was canceled. At present, the 6-ft-square hole is filled with barytes concrete blocks. It can be readily converted to another thermal column.

Shuttle Tubes

Two pneumatic shuttle tubes are provided, HR1 and HR2. These are 1-in.-ID horizontal tubes that extend completely through the structure and pass within 1 in. of the active lattice on the east side. These are in addition to HR3 and HR4, which approach the tank wall radially.

Any beam hole can be adapted to provide shuttle facilities. Pneumatic shuttle tubes are generally useful for short-time irradiations, varying from 1 sec to about 10 min. Since only air cooling is possible, care must be exercised that excessive heating does not occur.

Hydraulically-operated shuttle tubes are also provided. These are used for irradiations of small samples that require times from 5 min up to about 2 weeks or require insertion and removal between normal shutdowns. These shuttles consist of two 1-in.-ID tubes and two 1.31-in.-ID tubes running vertically through the reactor tank's bottom plug into the beryllium reflector adjacent to the active lattice. The hydraulic shuttles are loaded and unloaded under water in a short extension of the main canal in the reactor-building basement.

Design History of the MTR

1945, December: Design and development of high-flux reactor started at Oak Ridge National Laboratory.

1946, August: Preliminary design of MTR had crystallized. Final design and development were joint enterprise of ORNL and Argonne National Laboratory.

1949, July: Engineering design started by Chemical Plants Division of Blaw-Knox Construction Company.

1950, May: Ground broken at National Reactor Testing Station (Idaho) by The Fluor Corporation, Ltd.

1950, November: Phillips Petroleum Company appointed operating contractor under jurisdiction of AEC's Idaho Falls office.

1952, February: Reactor and plant ready for initial testing.
1952, March 31: Reactor achieved criticality.
1952, May 22: Full design power attained.

The MTR has operated smoothly for nearly 2 years with almost no loss of time due to shutdowns except those constituting a regular part of the operations program. For description of organization and staffing of operations project, see NU, March '53, p. 10.

Intensity and energy of γ-rays backscattered from various materials are important in many shielding, absorption, and counting problems. This article describes the scattered γ-rays as functions of the energy of primary γ-radiation and geometry

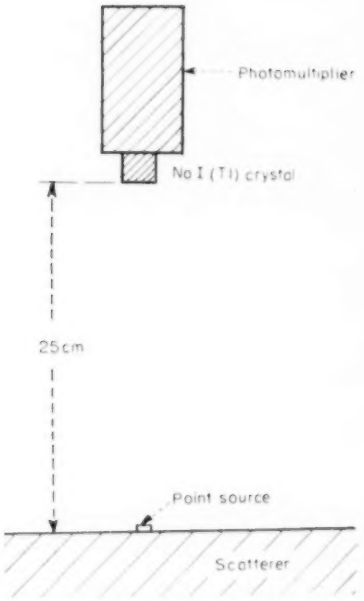


FIG. 1. Relative position of NaI (Tl) crystal, γ-ray source and scattering medium

By GERALD J. HINE* and RICHARD C. McCALL†
Department of Physics and Radioactivity Center of the Laboratory of Nuclear Science Massachusetts Institute of Technology Cambridge, Massachusetts

Gamma-Ray Backscattering

FOR EVERY primary γ-ray absorbed in matter by a Compton process, a scattered γ-ray of reduced energy is emitted. Scattered γ-rays that leave the absorber through the same surface the primary radiation entered are called backscattered radiation. Energy and intensity of backscattered radiation vary with the angle between primary and scattered radiation according to the Klein-Nishina formula. However, γ-rays backscattered from a finite absorber will show, in addition, absorption and multiple scattering effects.

Even though γ-ray backscattering becomes rather important for a variety of shielding, absorption, and counting problems, very few investigations concerned with γ-ray backscattering have been published.‡ The use of the scintillation γ-ray spectrometer allows systematic investigation of the intensity and energy of γ-rays backscattered from different materials, as a function of the energy of the primary γ-rays. Some of the fundamental properties of γ-ray backscattering will be described here.

Experimental Procedure

The experimental arrangement of γ-ray source, scattering material and NaI (Tl) crystal is shown in Fig. 1. Gamma rays absorbed in the NaI by photoelectric effect produce pulses proportional to their energy. For γ-rays absorbed by the Compton process, a continuous pulse spectrum of reduced energy is observed. The relative intensity of the two interactions depends on the energy of the incident γ-rays and the crystal size.

The pulse-height distribution is measured with a single channel differential pulse-height analyzer. Its base line is shifted very slowly and continuously from 3 to 100 volts. By

* Radioisotope Unit, Veterans Administration Hospital, Boston, Massachusetts.
† Public Health Service, Research Fellow of the National Cancer Institute.

‡ Evans Hayward, John H. Hubbell, Report 2264 (National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., 1953).

means of a precision counting-rate meter and linear recorder, the pulse height distribution is automatically recorded. If the paper on the recorder is reset so that a fixed relation exists between discriminator volts and paper position, a direct comparison of the pulse distributions obtained for different experimental conditions (different scattering materials) is possible. This superposition of the pulse spectra is time saving and allows a check on reproducibility of results and statistics to be improved. Finally, a direct energy calibration can be achieved by this method when the photoelectric peaks of several γ-ray emitters of known energy are superimposed.

No attempt was made to reduce scattering in the source itself or from the frame supporting the source and photomultiplier. The data labeled "no-backscatterer" were obtained under the following conditions. Thin threads kept the point source, consisting of radioactive material deposited on tape, in position 25 cm below the NaI (Tl) crystal and about 70 cm above the table (Fig. 1).

Two types of scattering experiments were performed. First, backscattering materials of different atomic numbers were placed in close contact with Hg^{203}, Cs^{137}, and Co^{60} sources. In the second group of experiments, aluminum was always used as scattering material, but the geometry of the scatterer and its position relative to the source were varied.

Various Materials

Lead, iron, aluminum, wood, and water were used as scattering materials. Wood and water gave about the same results. Figure 2 shows the γ-ray energy spectra obtained from Cs^{137} with various materials used as backscatterer. Since the Compton scattering cross section is proportional to the number of electrons per unit volume, scattering, in general, will be a maximum for scatterers with the highest atomic number. However, since the photoelectric absorption cross section increases very rapidly with increasing atomic number and decreasing photon energy, most of the scattered quanta suffer a photoelectric absorption before they can escape from a scatterer of high atomic number. As a result of these two competing processes, there will be elements for which the intensity of the observed scattered radiation is greatest. Figure 2 shows that aluminum produces the greatest increase in the intensity of the low energy part of the spectrum. On the other hand, the lead backscattering curve nearly coincides with the spectrum obtained with no backscatterer, with the exception of the very low energy peak due to the lead fluorescence radiation.

Figure 3 shows an identical experiment with Hg^{203} as a low energy γ-ray source. The low energy parts of these spectra consist not only of backscattered radiation but also of the thallium K X-rays and, in the case of the lead backscatterer, of the lead fluorescence radiation. Curves obtained with Co^{60} γ-rays show backscattering-effects similar to the Cs^{137} curves.

From these experiments with various materials it may be seen that scattering effects can be minimized by using lead or lead-coated materials.

Figure 2 shows that scattered radiation is grouped in two definite peaks rather than in a continuous distribution such as might be expected. The reasons for these discrete peaks will be discussed after describing the variable geometry experiments.

Variable Geometry

In this second set of experiments with Co^{60} γ-rays, aluminum was chosen as scattering material. Thickness and area of scatterer were varied. Figure 4 shows the marked changes in spectra caused by increasing the thickness of a 4-in.-square aluminum backscatterer from $\frac{1}{8}$ to 3 in. If the thickness of aluminum scatterer is increased beyond 2 in., the scattered intensity increases very little. A similar set of curves is shown in Fig. 5, where the thickness of a set of cylindrical aluminum scatterers is 2 in. and their diameter varies from 1 to 11 in.

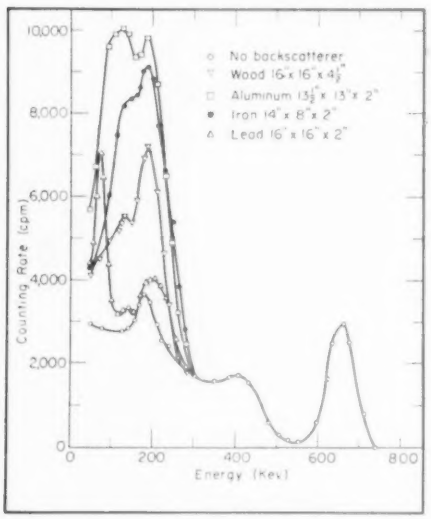


FIG. 2. Pulse energy spectrum from the 661-Kev γ-rays of a Cs^{137} point source in contact with various scattering materials

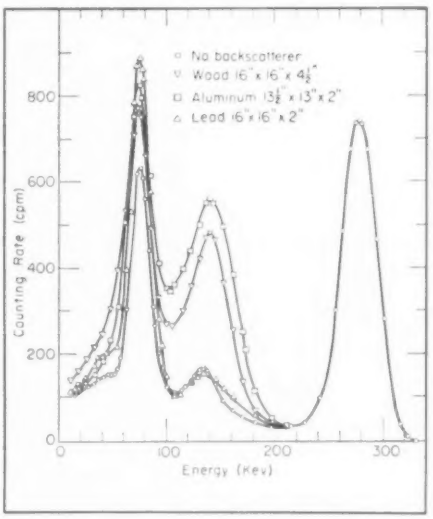


FIG. 3. Pulse energy spectrum from the 280-Kev γ-rays of a Hg^{203} point source in contact with various scattering materials

The scattered intensity still increases with the largest area that can be fitted into the experimental arrangement. Further increase can be expected when using even larger scattering areas.

Theory

A qualitative theoretical explanation of these results will be derived.

The energy of a γ-ray after a Compton collision is given by

$$h\nu_s = \frac{m_0c^2}{(1 - \cos\theta) + \frac{m_0c^2}{h\nu_0}} \quad (1)$$

where $h\nu_0$ = energy of the primary photon, $h\nu_s$ = energy of the scattered photon, $m_0c^2 = 0.511$ Mev = rest energy of the electron, and θ = angle between directions of primary and scattered photon. From Eq. 1, the ratio of the energy of the scattered photon to the primary photon is

$$\frac{h\nu_s}{h\nu_0} = \frac{1}{1 + \frac{h\nu_0}{m_0c^2}(1 - \cos\theta)} \quad (2)$$

The ratio given by Eq. 2 is a function not only of θ, but also of the energy of the primary photon. Therefore, isotopes emitting γ-rays of various energies have been used in these experimental investigations.

Figure 6 shows the ratio of the energies of the scattered to the primary γ-ray as a function of scattering angle θ and for various values of the primary γ-ray energy as given by Eq. 2.

Figure 7 illustrates the angles involved in a Compton backscattering collision where the scattered γ-ray strikes the crystal. The primary γ-ray has an initial direction defined by the angle ϕ. Only a small range of possible values of the scattering angle θ will cause the scattered γ-ray to strike the crystal and be recorded. By examining Fig. 7, it can be seen that these values of θ must be somewhat larger than $180° - \phi$. That is

$$\theta \geq 180° - \phi, \; \phi \leq 180° - \theta$$

Figure 6 shows that for all energies of the primary γ-rays, the energy of the scattered γ-ray is nearly constant for θ greater than 140° ($\phi \leq 40°$). Thus, those γ-rays emitted from the source within the cone defined by apex angle $2 \times 40°$, or 0.468π steradians, will have nearly the same energy as the 180° backscattered γ-rays if detected by the crystal after a single scattering. Since this solid angle covers 23% of the total scatterer illuminated by the source and the rest of the scattered γ-rays detected have a broad energy distribution, the spectrum of the scattered γ-rays will have an intensity maximum at an energy close to that of the 180° backscattered radiation. The table shows that the observed energy of the scattering peaks agrees with the calculated energy of the 180° backscattered radiation for the different isotopes used in Figs. 2–5.

Since the experiment's geometry prohibits detection of any γ-rays scattered through less than 90°, the spectrum should remain unchanged above the energy corresponding to a 90° single scattering. Due to the finite size of the crystal, some γ-rays scattered through slightly less than 90° are actually counted. Comparison of the table and Figs. 2–5 shows good agreement of theory and experiment.

The lower energy peak of the scattered γ-rays is found to be of an energy lower than that of a γ-ray that has lost the maximum amount of energy by a single Compton collision ($\theta = 180°$). Therefore, it must be due to double or multiple Compton scattering, which cannot be distinguished in these experiments. If a γ-ray, first scattered through an angle θ_1, is then scattered through an angle θ_2, its energy will depend on both scattering

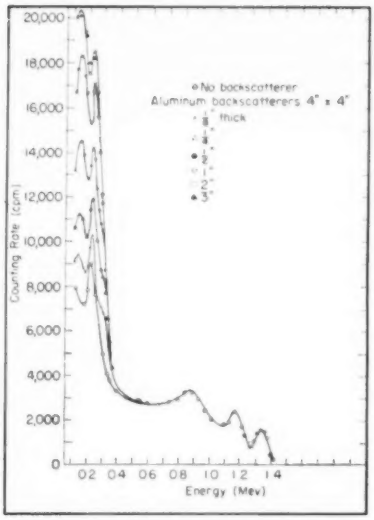


FIG. 4. Pulse energy spectrum of Co^{60} γ-rays from a point source in contact with aluminum scatterers of different thicknesses. Background has not been subtracted

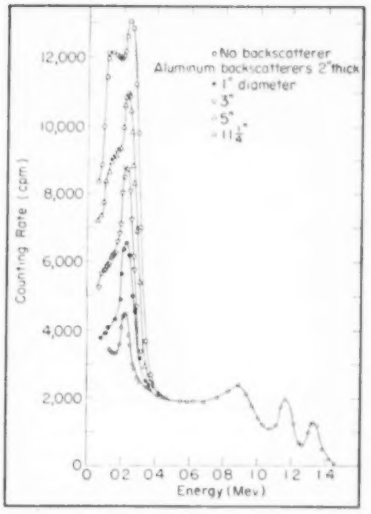


FIG. 5. Pulse energy spectrum of Co^{60} γ-rays from a point source in contact with 2-in. thick aluminum cylinders of different diameters. Background subtracted

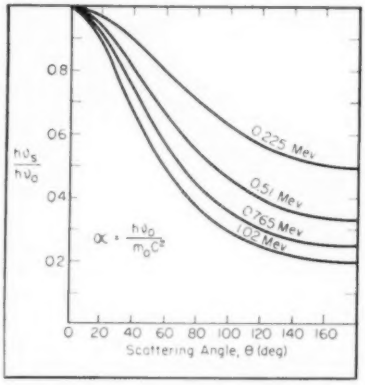


FIG. 6. Ratio of the energy of the scattered γ-ray to that of the primary γ-ray as a function of scattering angle θ and for various values of primary γ-ray energy

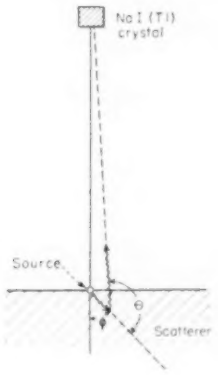


FIG. 7. Compton collision where the scattered γ-ray strikes the crystal. Angle between primary γ-ray and crystal-source centerline = ϕ. Angle between primary and scattered γ-ray = θ

Calculated Energy of Backscattered Radiation

Isotope	$h\nu_0$ (Mev)	Max. energy of Compton electron (Mev)	Single scattering $h\nu_s$ (Mev) Scatt. 180°	Scatt. 90°	Double scattering* Angle of first scattering 90°	180°
Hg^{203}	0.280	0.146	0.134	0.181	0.106	0.088
Cs^{137}	0.661	0.477	0.184	0.288	0.135	0.107
Co^{60}	1.17	0.960	0.210	0.356		
	1.33	1.116	0.214	0.369	0.157	0.116

* Angle of second scattering = 180°

angles. The double-scattered γ-ray can have an energy lower than that of a γ-ray singly scattered through 180° (see "double scattering" in table).

The geometrical limitations imposed for detection of singly scattered γ-rays no longer exist for double scattering. Therefore, it seems that the double scattering peak is not a true peak but a broad distribution of pulses that is sharply attenuated on the lower energy side by photoelectric absorption within the scatterer (Figs. 2-5). Reference to absorption coefficient curves for the various materials shows that the photoelectric absorption coefficient increases very rapidly for γ-ray energies below 0.1 Mev. This explanation is further substantiated by the fact that the double scattering peak for Hg^{203} (energy ≈ 88 Kev) is very small (see Fig. 3).

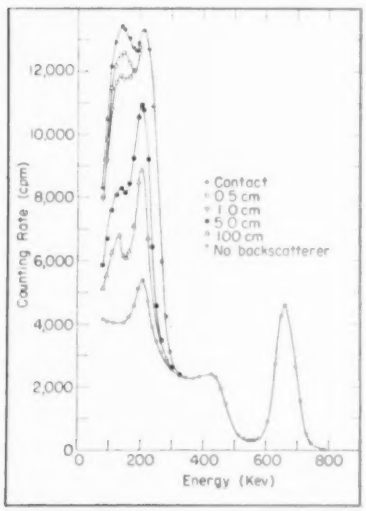


FIG. 8. Pulse energy spectrum of Cs^{137} γ-rays from a point source with aluminum backscatterer at various distances behind it

Source-Scatterer Distance

An experiment was performed to check the preceding theory. The Cs^{137} source was held in a fixed position with a large (12 × 12 × 2 in.) aluminum backscatterer at a variable distance behind it. The γ-ray energy spectrum was measured as a function of the distance between source and backscatterer. The results are shown in Fig. 8.

It has been shown in preceding paragraphs that those γ-rays that produce the single-scattering peak are initially directed in a fairly small cone with axis perpendicular to the backscatterer. Increasing the separation of the source and backscatterer increases the area this cone of γ-rays illuminates on the large aluminum scatterer. However, this causes only small changes in the scattering angle necessary for the scattered γ-ray to strike the crystal. The solid angle of the crystal as seen from the backscatterer decreases as the source-scatterer separation increases; so fewer scattered γ-rays will strike the crystal. Therefore, the intensity of the single-scattering peak decreases slowly, but its energy remains constant.

The multiple scattering peak is caused to a large extent, by those primary γ-rays initially directed outside the cone. As the source and backscatterer are separated, more and more of these γ-rays will miss the backscatterer, producing a rapid decrease in the intensity of the multiple-scattering peak.

Conclusions

The observed pulse energy distribution is a function of both the energy of the incident γ-rays and the response of the NaI (Tl) crystal to γ-rays of various energies. Thus, the observed spectral energy distribution of primary or secondary γ-rays is not a true representation of their relative intensity. The pulses caused by scattered radiation can be distinguished from those produced by primary radiation by comparing the pulse distributions obtained from a source alone and the source with a scattering medium near by. By changing the dimensions of the scattering medium one can investigate the contribution from various parts of the scatterer. Geometrical and energy considerations allow us to distinguish between single and multiple scattered radiation and to give a quantitative interpretation of the various experimental findings.

High atomic-number materials like lead are poor scatterers for γ-rays of all energies. This is caused by their high photoelectric absorption of the lower-energy scattered γ-rays. The emission of characteristic fluorescent radiation produced by the photoelectric absorption process is observed.

* * *

The authors are indebted to Miss Virginia K. White for valuable technical assistance.

This work has been supported in part by the joint program of the Office of Naval Research and the Atomic Energy Commission.

Progress on Reactor Safety

It has been recognized for a long time, since the very beginning of this business over ten years ago, that reactor location is an important problem and is a difficult problem. Progress has been made and is being made, and it does not follow that reactors which were designed early in the technology would have the same degree of safety, so to speak, as the ones that could be designed now. I believe that it is a design problem and with effort and work the penalty to get the necessary safety will diminish finally to where it won't be an important item.

—*W. H. Zinn, before National Industrial Conference Board, N. Y. C., Oct. 1953*

The Biological Effectiveness of Thermal Neutrons on Mice—II

Biological effectiveness of 1.37 x 10^{10} n/cm^2/rem was found for neutrons of the "Water Boiler" thermal column compared with 250-kvp X-rays. Corrections were made for gamma contamination and neutron-sink effect of the mouse group

By JAMES T. BRENNAN,*
PAYNE S. HARRIS,†
ROBERT EMERSON CARTER,
and WRIGHT H. LANGHAM
Los Alamos Scientific Laboratory of the University of California Los Alamos, New Mexico

INHERENT GAMMA CONTAMINATION of the Los Alamos homogeneous reactor thermal column was discussed in Part 1 of this article (NU, Feb. '54, p. 48). The purpose of the biological measurements, described in this second part, was to determine R (total biological response in the live mice) and γ_c (biological effectiveness of the thermal-column gamma contamination in rem/sec).

Measurement of ξ

When 15 mice are placed in the thermal-column exposure cavity, they constitute a neutron sink and, therefore, further reduce the inherent gamma contamination (γ_c). However, this influence must be a small one since the indirect gamma-depressing effect of the 15 mice cannot be greater than that due to the smallest cylindrical lithium shield‡ (3.6 cm, see Fig. 15). Accordingly, the inherent gamma dose rate to which the mice were subjected is taken to be the same as the dose rate inside the bismuth with no mice present, i.e., 24.3 r/min.

Even though the 15 mice do not produce a significant depression of γ_c in the region of the cavity, it is still possible that, within the small volume occupied by the mice, the neutron flux is significantly depressed by neutron capture in mouse tissue. Indium foils were used to investigate this point.

Indium foils exposed with dead mice. Three In foils were placed in the graphite cage along with 15 dead mice. One foil was on the center mouse of the middle tier and the other two were on the periphery of the mass of mice. Under these circumstances the fluxes observed (n/cm^2/sec) were 1.21×10^{10} in the center tier, 1.50×10^{10} in the upper tier, and 1.44×10^{10} in the lower tier, indicating neutron shielding of 33%, 16%, and 19%, respectively. On the average, the flux received by each mouse exposed in a group of 15 mice was 21% less than the flux measured in the empty cavity. Thus $\xi = 0.79$.

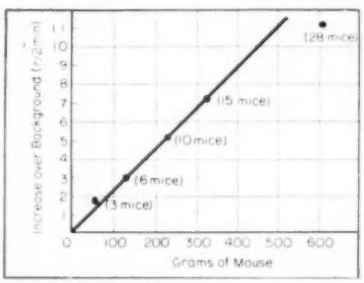


FIG. 20. Intermouse gamma-source strength

Measurement of γ_i

A mouse placed in a thermal-neutron flux becomes a gamma source. By using the experimental arrangement shown in Fig. 19,* it was possible to measure this intermouse gamma effect.

The measurements were begun with the graphite mouse cage empty; r-meter readings were taken as dead mice were added to the cage (Fig. 20). The ion-chamber reading was due to the inherent γ-rays in the column plus the radiation dose resulting from the mice becoming a gamma source.

Fifteen dead mice (317 gm) caused an increase of 7.02 r/min in the gamma dose received by the ion chamber. Each mouse was therefore responsible, on the average, for an increase of 0.23 r/min. The average distance from the center of a mouse to the center of the ion chamber was 9.2 cm.

Source strength of mouse. From these results, it is possible to calculate the gamma source strength per mouse as follows:

Hydrogen-capture γ-rays give a dose rate of 9.9 r/mc/hr at a distance of 1 cm (*13*). The source strength of each mouse is, therefore, $(0.23)(60)(9.2)^2/9.9 = 117$ mc.

Each mouse in a group of 15 was irradiated by 14 such sources. The average distance between mice was 6.3 cm. The total intermouse gamma dose received by each mouse is then

* Lt. Col., USA MC, Walter Reed Army Medical Center, Army Medical Service Graduate School, Washington, D. C.

† Major, USA MC, Assigned 8452nd SWG, Sandia Base, New Mexico.

‡ Metallic lithium reacts violently with water and crumbles if left exposed to air. It must be handled with gloves and stored in mineral oil.

* Figures 1–19 are in Part 1 of this article (NU, Feb. '54, p. 48).

FIG. 21. Method of exposing mice to 250-kvp X-radiation

FIG. 22. Method of measuring radiation dose rate with mouse phantoms

$(14)(117)(9.9)/(6.3)^2(3,600) = 0.11$ r/sec.

If it is assumed that 2.2-Mev γ-rays have an RBE of 0.80, then the inter-mouse gamma dose received by each dead mouse is $(0.11)(0.80) = 0.09$ rem/sec.

It should be noted that this dose-rate of 0.09 rem/sec applies to the dead mice that were exposed in the presence of an added neutron sink in the form of the five-layered Li shield (see Fig. 19). This added sink was *not* present when the live mice were exposed. According to the foil data, the dead mice by themselves reduced the neutron flux by 21%. The magnitude of the sink effect of the five-layered Li shield (1.85 cm Li) may be seen in Fig. 15, where the reduction in cavity-neutron gamma flux is 25%.

Net neutron sink. If the two neutron sinks are considered to function independently of each other, then the net effect would be to reduce the neutron flux reaching the dead mice by about 41%. Thus the neutron flux reaching the dead mice would be $(1.8 \times 10^{10})(0.59) = 1.06 \times 10^{10}$. From theoretical considerations (*13*), a mouse in such a thermal-neutron flux should have a gamma source strength of 119 mc. This is to be compared with the measured source strength of 117 mc. This agreement provides a crude experimental verification of the equation employed by Mayneord (*13*) and also provides a rough check on the interpretation of ion chamber readings given in the present report.

In the case of the live mice, the inter-mouse gamma dose was somewhat greater than in the case of the measurements made with the dead mice because in the former instance the Li sink was not present. The increase is $\gamma_i = (0.79/0.59)(0.09) = 0.12$ rem/sec.

Handling of Mice

Sixteen hundred female Swiss mice, obtained from a commercial source, were used in the experiment. The mice were 8–11 weeks of age at the time of exposure. After a 1–2 week period of acclimatization, the 1,600 animals were randomized by placing them in a large open-top box from which they were reassigned to cages according to a table of random numbers. The animals were caged in groups of 15 with food and water in constant supply.

The X-ray exposures required 1½ days, and the thermal column exposures required 2½ days. All exposures were accomplished within a period of 3 days except in a few cases.

Forty-five mice were exposed at each dose level. The mice exposed in the thermal column were exposed in groups of 15. The animals that received X-rays were exposed in two groups of 23 and 22 each.

During the first two weeks of the experiment, all cages were checked at least twice daily and the number of dead mice recorded. Control groups of mice received at all times exactly the same handling as that accorded the irradiated mice. No deaths occurred among the controls, and there was no evidence of endemic or intercurrent disease.

X-Ray Exposure Technique

The X-ray machine used was a Picker 250-KVP industrial-type unit with a ripple voltage. The arrangement employed for exposure of animals is shown in Fig. 21. Operating characteristics of the machine and the exposure conditions were: 250-kv peak voltage, 15-ma, 3-mm Al inherent filtration, 0.33-mm Cu + 0.83-mm Al added filtration, 2.0-mm HVL in Cu, 59.6-r/min dose rate (free air), and 55-cm target-to-specimen distance.

The dose rate in the thermal column was thought to be of the order of 80 rem/min. It was desirable, therefore, to have the X-ray dose rate approach this value as closely as possible.

The X-ray dose rate was measured in air with the mice and cage removed from the beam, and the center of the ion chamber was placed at that point in space formerly occupied by the center of the top surface of the mouse cage. Three different Victoreen 100-r chambers were used, and two 1-min measurements were made with each. Before the experiments were started, the ion chambers and electrometer were calibrated by the National Bureau of Standards.

The dose rate was calculated by applying the appropriate temperature, pressure, and chamber corrections. The mean of the six measurements was 59.6 r/min with a variation of ±3%. Periodic checks of the dose rate during the days on which exposures were made showed no significant variations. Measurement of the dose rate at the center of the top surface of the cage, with the cage filled with masonite mouse phantoms (Fig. 22), gave a value of 65.5 r/min, which was an increase of 9.9% over the measurement made in free air. In keeping, however, with past practice, the radiation dose measured in free air is used in this report. The variation in dose rate across the beam was checked to be sure that the edges of the cage were within the beam. Table 2 shows the X-ray doses administered and the 30-day mortality in each group. These data are shown graphically in Fig. 23.

Exposure in Column

The biological exposure cavity was formed by four pieces of high-purity pile graphite (Fig. 9). When in position, the center of the cage was at point *P* in Fig. 1. This cage was made of ½-in. graphite, mortised and assembled with graphite screws.

The cage was loaded with seven mice in the middle tier and four mice each in

the upper and lower tiers. The air holes were adequate and air was supplied through a rubber hose (Fig. 2). All mice exposed in the middle tier were marked to see if the position in the cage had any influence on survival.

The exposure times and the 30-day mortality in each exposure group are given in Table 2 and in Fig. 24. Some low-dose groups were included for a study of the chronic effects of a single exposure of thermal neutrons. These mice, as well as the survivors from the higher dose groups, are being observed for cataracts, tumor incidence, and life span.

The exposures for lethality studies were made at a power level of 25 kw determined from the control board. The build-up to power is exponential in time; to compensate for the dose received during build-up, timing was started at 8 kw. Shut-down of the reactor at the end of a run was considered to be instantaneous.

The assembly used for exposing the mice in the thermal column included the double-layered bismuth shell seen in Figs. 2 and 9. With the two bismuth lids in place, this shell provided a continuous shield, 1 in. thick, which served to reduce the inherent γ-ray dose received by the mice. The physical measurements showing the effect of this shield were discussed in Part 1.

Lethality Responses

The probit lines of Figs. 23 and 24 provide the best method of comparing the slopes of the two dose-response curves and also provide the most accurate determination of the LD-50 dose. The slopes of these two probit curves are not significantly different as may be seen from the probit equations, or by superimposing the two curves.

The LD-50 values obtained from the equations given in Figs. 23 and 24 were 486 r of X-ray and 356 sec of thermal-column exposure. Thus $R = 486/356 = 1.37$ rem/sec.

The data in Table 2* show the survival times of mice exposed to both types of radiation. From these data, the mean survival times of the dead mice of any group may be calculated. Doses of X-rays and thermal-column radiation that were comparable, in the sense that they caused the same per cent mortality in 30 days, differed

* Table 1 is in Part 1 of this article (NU, Feb. '54, p. 48). The curve of Fig. 5 is based on the data in Table 1.

TABLE 2—Survival Times of Mice Exposed to 250-kvp X-rays and to Thermal-Column Radiation

	Days after exposure and number of animals dying per day at each dose																											*Total*
Exposure	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*dead*
250-kvp X-rays																													
(r)																													
200																													
300																													
400													2				1			1									4
450							1		1	1	1		1	1			1							1	1				9
500					1		1	1	1	4	4		1	2	1	1			1	1	1			1			1	1	23
550							2	1	3	4	4	7	1	3		2	1		1		1	1							31
600			1	1	1	2	3	4	8	2	6	5	5	1	2						1	1							43
650						1		2	4	3	3	6							1										20
700						4	6	12	6	9	6	1							1	X									45
800			1	1	2	3	6	13	11	4	3		1	X															45
900		3	3	5	8	6	7	2	9	X																			43
1,100		12	18	6	7	1	1	X																					45
	3	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	
Thermal-column irradiation																													
(sec)																													
144																													
225									1				1																2
300							1					1												1				1	4
325								1	1	1	2	1	2	1	1	1													11
350							3	1	2		1			1	1				2	1								1	13
375					1	3	1	4	4	3	1	4			2	3		3			2			1	1				33
413		1	2	7	4	3	2	5	6	1	1		2	1			1				1	1			1	1			40
450		2	3	7	6	4	4	4	2	6	3	1	2	1	X														45
487		10	9	4	6	8	3	2	1		2	X																	45
525		19	10	7	4	2	1	2	X																				45
600	1	27	10	1	4	2	X																						45
675	2	33	9	1	X																								45
825	2	28	13	2	X																								45
975	4	24	12	5	X																								45
1,055	3	12	X																										15

Note: X indicates death of all animals in the exposure group.

slightly in that the mice that received thermal-column radiation showed a tendency to die earlier.

Movement During Exposure

In the calculations employed above, it was assumed that by moving about during exposure the mice effectively averaged out among themselves the 21% neutron-shielding effect observed. This is highly probable since it was observed that with an air stream blowing on the graphite cage the mice tend to move about actively.

When deaths were scored, the deaths that occurred among animals exposed in the middle tier were tallied separately. If exposure in the middle tier introduced no bias in the results, the ratio of deaths among animals exposed in the upper and lower to the middle tiers would be 8/7 = 1.14. With only those groups of mice considered in which a fractional mortality occurred, there were 47 deaths among mice exposed in the middle tier and 56 deaths among mice exposed in the upper and lower tiers. The ratio is 56/47 = 1.20. This result is consistent with equalization of dose due to movement of mice during exposure.

Measurement of γ_e

From the results of Part 1, it is evident that the effectiveness of the thermal-column gamma contaminant can be investigated by exposing mice inside a lithium shield thick enough to exclude the thermal neutrons.

Three groups of 15 Swiss mice were exposed in the graphite cage inside the six largest Li shells shown in Fig. 7. The end plug of the solid bullet-shaped Li shield was used to cover the open end of the shell assembly.

The measured dose rate inside the Li was 27.2 r/min. Three exposures of 18 min and 11 sec were made, each to deliver a dose of 494 r, which was estimated to be the LD-50 of X-rays.

In the ensuing 30 days, none of the exposed mice died. They did, however, show signs of radiation sickness. This rather surprising result indicated that the inherent γ-rays of the thermal column had a very low biological effectiveness relative to X-rays, and made it necessary to repeat the study.

CF-1 mice. No more Swiss mice were available, but there were available 90 CF-1 mice from a group for which the X-ray LD-50 dose was known to be 492 r. Two groups of 45 of these CF-1 mice were exposed in subgroups of 15 inside the six Li shells. The dose rate was again measured as 27.2 r/min. The exposures were increased to 27 min and 36 min to deliver doses of 734 r and 979 r, respectively. The two groups were observed for 30-day mortality.

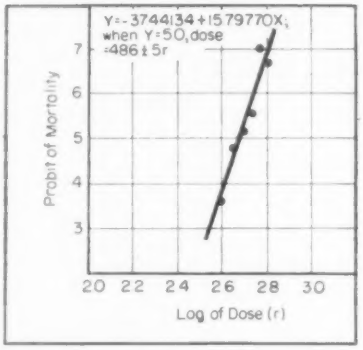


FIG. 23. Probit analysis of 30-day mortality in Swiss mice exposed to 250-kvp X-radiation

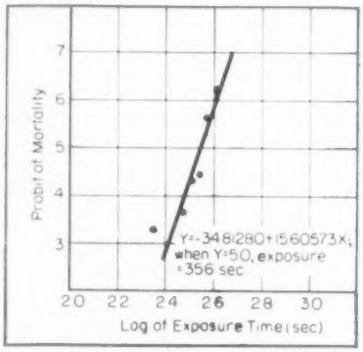


FIG. 24. Probit analysis of 30-day mortality in Swiss mice exposed to the mixed radiation of thermal column

The results for the 734-r and 979-r doses were 13% and 62%, respectively. A plot of these two points indicates a 30-day LD-50 of ~920 r, and the RBE of the gamma contaminant is 492/920 = 0.53. This value is quite low. However, comparable values have been found for 22-Mev betatron X-rays (*14*).

It was shown earlier that the gamma-contaminant dose rate received by the Swiss mice in the Bi shield was 24.3 r/min.

If 0.53 is taken as the correct RBE for the inherent γ-rays of the column, then the measured dose rate of 24.3 r/min must be changed to $\gamma_e = 24.3 \times 0.53/60 = 0.21$ rem/sec, before being applied as a correction factor.

The results obtained with the mice exposed inside Li serve to rule out the presence of a biologically significant fast-neutron flux in the thermal column at the point of exposure. This conclusion follows from the fact that fast neutrons are relatively inefficient in discharging a Victoreen 100-r chamber. The use of the *n* unit for neutron dose (*15*) is based upon the idea that a reading of 1 r on a Victoreen chamber exposed to fast neutrons indicates a dose of about 10 rem. Consequently, in the present experiment, instead of getting a low RBE of 0.53, an RBE much greater than 1.0 would have resulted had an appreciable part of the r-meter reading been due to fast neutrons.

RBE of Thermal Neutrons

From the foregoing we have that

$$F = \frac{(nv)\xi}{R - \gamma_e - \gamma_i} = \frac{(1.8 \times 10^{10})(0.79)}{1.37 - 0.21 - 0.12} = 1.37 \times 10^{10} \text{ neutrons/cm}^2\text{/rem}.$$

Obtaining this value was the principal purpose of this experiment.

This calculation tacitly assumes that the radiations involved are additive in simple linear fashion. This assumption has been supported by subsequent work (*16*).

Calculation of rep. Various ionizing radiations are usually compared by means of their relative biological effectiveness or "RBE," which is defined as the ratio rem/rep. In the present work, no attempt was made to measure rep. Therefore, if it is desired to get the RBE of thermal neutrons, it is necessary to make a calculation of rep.

In dealing with a similar situation, Conger and Giles (*8*) presented a formula by means of which one may calculate the dose in rep delivered to a small mass of tissue by a thermal-neutron flux. Slightly modified, the equation giving the dose in rep/sec for any particular constituent element is

$$\text{rep/sec} = \frac{(nv)N\sigma_c(E \times 10^6)(A)}{5.85 \times 10^{13}}$$

where 1 rep = 93 ergs/gm, nv = thermal neutrons/cm²/sec, N = number of atoms of the element per cm³ of tissue, σ_c = the capture cross section for thermal neutrons in cm², E = energy in Mev of the radiation(s) emitted by the element after neutron capture, and A = the fraction of E that is absorbed in the specimen.

For protons and alpha particles, $A = 1$, but for the capture γ-rays from

hydrogen, A is, of course, much less than 1. For hydrogen capture γ-rays in the mouse, $A = (1 - e^{-\mu_a t G})(L)$, where μ_a = the absorption portion of the total Compton coefficient for 2.2-Mev γ-rays in tissue = 0.023 cm^{-1}; t = the radius of a mouse, considering one mouse to be a sphere of 21 cm^3 volume (t = 1.7 cm); G = a geometric factor relating the mean escape path length in the volume of a sphere to the radius of the sphere (G = 0.75); and L = elongation factor to correct for the fact that the mouse is not a sphere but a cylinder whose length is three times its diameter (L = 0.87) (*13*).

For the mouse, then, $A = 1 - e^{-(0.023)(1.7)(0.75)}(0.87) = 0.025$. Or, in other words, only 2.5% of the hydrogen-capture gamma energy created within the body of a mouse is absorbed in that mouse.

With the formula above it is easily shown (*8*) that, among the abundant elements in tissue, only hydrogen and nitrogen make a significant contribution to thermal-neutron dose.

Among the elements present in trace amounts in tissue, Conger and Giles (*8*) and Conger (*17*) found that, in *Tradescantia*, only boron was of any importance. In material containing 0.00028% boron by weight, 32.3% of the total energy absorbed from thermal neutrons was attributable to capture in boron. Thus there arises the question of the boron content of mouse tissue. Vogel and Telford (*18*) found mouse tissue to contain 0.00038% of boron by weight by colorimetric analysis. In the present experiment, a spectroscopic analysis of the ash of a whole mouse showed <0.001% boron and <0.001% lithium. This was followed up with colorimetic quantitative analyses as follows:

The G. I. tracts were extirpated from two mice and discarded. The remainder was ashed and analyzed for boron and lithium. Parallel determinations were made on the ash from 40 gm of dry mouse food. The results were, for the mice minus G. I. tract, 0.0001% B and 0.0000004% Li, wet weight; the food contained 0.0020% B and 0.0002% Li, wet weight.

In the following considerations, the value of 0.0001% boron on the basis of wet weight is used. With the relatively high boron content of mouse food, the gut epithelium may receive a high alpha dose.

The nitrogen content of mouse tissue was taken to be 3% by weight and the hydrogen content 10%. Substitution of these values in the equation for calculating rep/sec gives:

Hydrogen

rep/sec
$= (1.42 \times 10^{10})(6.02 \times 10^{22})(0.32 \times 10^{-24})(2.2 \times 10^{6})(0.025)/5.85 \times 10^{13}$
$= 0.257$

Nitrogen

rep/sec
$= (1.42 \times 10^{10})(1.29 \times 10^{21})(1.7 \times 10^{-24})(0.62 \times 10^{6})(1)/5.85 \times 10^{13}$
$= 0.330$

Boron (assuming homogeneous distribution)

rep/sec
$= (1.42 \times 10^{10})(5.6 \times 10^{16})\ (720 \times 10^{-24})(2.35 \times 10^{6})(1)/5.85 \times 10^{13}$
$= 0.023$

Total = 0.61 rep/sec. The RBE of thermal neutrons is then (total rem/sec)/(total rep/sec) = 1.04/0.61 = 1.70.

If the RBE of the 2.2-Mev hydrogen-capture γ-rays is taken to be 0.8, then the dose due to this component is (0.257)(0.8) = 0.206 rem/sec. Then the per cent of total thermal-neutron dose due to H-capture γ-rays is (0.206/1.04) × 100 = 20%. The effective or combined RBE of the nitrogen protons and boron alpha particles is (rem/sec)/(rep/sec) = (1.04 − 0.206)/(0.33 + 0.023) = 2.36.

The term RBE has been defined (*19, 20, 21*) as the ratio rem/rep, where the baseline or comparison radiation is radium γ-rays filtered by 0.5 mm of platinum. The present experiment, in which the baseline radiation is 250-kvp X-ray, was well under way before the radium-baseline definitions of RBE were published. Moreover, it would have been necessary, in any case, to use X-rays as the baseline radiation in the present experiment to obtain the dose rate desired. If it has been possible to use radium gamma as the baseline radiation, the RBE's obtained would, presumably, be higher.

Other Biological Experiments

Conger and Giles (*8*), observing visible chromosome aberrations in *Tradescantia* inflorescences, found 5×10^7 thermal neutrons/cm^2 equivalent to 1 r of X-radiation. This differs from the present result by a factor of 2.7. There are many possible reasons for this difference, but the most likely explanation is that two widely different kinds of biological response were being observed.

In 1944, Zirkle and Raper (*5*) found that the LD-50 (21 days) in CF-1 mice was obtained with a dose of 4.2×10^{12} thermal neutrons/cm^2. Under the conditions of their experiment, thermal neutrons were estimated to account for about half of the total effect. To compare their result with the results given in this report, it is necessary to choose some value for the LD-50 (21 days) for CF-1 mice exposed to 250-kvp X-rays. If this dose is taken to be 500 r, then their experiments showed that 4.2×10^{12} thermal neutrons/cm^2 gave an effect equivalent to 250 r or 1.7×10^{10} thermal neutrons/cm^2 = one rem. This value compares with 1.37×10^{10} thermal neutrons/cm^2 = 1 rem found in the present experiment.

* * *

This article is based on a paper presented before the Symposium on the Biophysical and Biological Effects of Neutrons, sponsored by the Division of Biology and Medicine, U. S. Atomic Energy Commission, March 17, 1952, Washington, D. C., and reported as LA-1408 (1952).

In an experiment involving a reactor, one is inevitably completely dependent upon the people who operate the reactor. It is a pleasure to express our appreciation of the unstinting cooperation we received from the members of Group P-2, LASL, who built, operate, and maintain the water boiler. In particular we wish to thank the group leader, L. D. P. King, Mrs. B. Warren, J. W. Starner, W. E. Stein, John E. Evans, J. R. Phillips, J. R. Beyster, and Bob Watt.

The chemical analyses reported herein were performed by Charles F. Metz and O. R. Simi of Group CMR-1, LASL.

During the early stages of this work we had the advantage of consultation with Dr. R. E. Zirkle of the Institute of Radiobiology, University of Chicago, and with Dr. Robley Evans of the Massachusetts Institute of Technology.

Invaluable assistance with the exposures and with the observation and scoring of mice was rendered by Mrs. Phyllis Sanders, Mrs. Julia Wellnitz, and Robert Schuch of Group H-4, LASL.

BIBLIOGRAPHY

Note: References 1–12 appeared in Part One of this article (NU, Feb. '54, p. 48).

13. W. V. Mayneord, Supplement No. 2, *Brit. J. Radiol.*
14. H. Quastler, R. K. Clark, *Am. J. Roentgenol. Radium Therapy* **64** (1945)
15. P. C. Aebersold, G. A. Anslow, *Phys. Rev.* **69**, 1 (1946)
16. P. S. Harris, J. B. Storer, LA-1502 (1952)
17. A. D. Conger, *Genetics* **38**, 2, 128 (1953)
18. H. H. Vogel, R. E. Telford, USAEC Bio-Medical Program Directors Meeting, Argonne National Laboratory (May, 1951)
19. H. M. Parker, *Radiology* **54**, 2, 257 (1950)
20. Handbook 47, p. 18 (National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., 1950)
21. Handbook 52, p. 44 (National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., 1953)

OPERATOR sets network resistors of NACA reactor simulator after adjusting initial current with resistors on measurement panel (right) during solution of the multigroup approximation to the neutron age equation. Construction, theory and operation of this unit are described for reactor designers in this article about . . .

Using a Reactor Simulator for Design Analysis

By R. B. SPOONER*
Nuclear Applications Group
The Glenn L. Martin Company
Baltimore, Maryland

CRITICALITY CONDITIONS and spatial distribution of neutrons in a reactor are generally calculated using a multigroup approximation of the neutron age equation (*1, 2*). The reactor simulator described in this article rapidly gives solutions for the numerical integration of the unidimensional multigroup approximation. The simulator is a linear electrical resistance system of flexible design.

Equations will be developed to demonstrate the analogies between electric currents in the network and neutron processes in a reactor, as well as between resistor values in the network and neutron diffusion properties of reactor materials.

NACA Simulator

The simulator at the Lewis Laboratory (Cleveland) of the National Advisory Committee for Aeronautics (NACA) is a linear electrical resistance network. The resistor values chosen depend on the nuclear properties

* Until recently the author was a member of the engineering staff of the National Advisory Committee for Aeronautics, Cleveland, O.

(diffusion, slowing, absorption, etc.) of the reactor materials for neutrons of successive energy groups. Electric currents measured in the network then directly simulate neutron processes for the neutron energy group under investigation.

The simulator was designed as a flexible tool for rapidly performing design studies for various reactor configurations. The accuracy desired permitted simplification through a reduction to one dimension and to finite spatial intervals. However, the range of reactor types under study necessitated a simulator capable of giving either two-group or multigroup approximations—depending on the reactor structure and the neutron energy spectrum. The simulator, therefore, is a linear electric network having variable and interchangeable circuit elements so as to provide an approximation to the multigroup equation conditions. One neutron energy group is treated at a time, as in the numerical calculation procedure.

Figure 1 is a simplified schematic diagram of the electric network and reactor segment for which the simulator provides a neutron distribution solution. It shows the correspondence between reactor volume elements and electric network sections. To simulate the birth or the slowing of neutrons into the particular energy group for which a solution is required, initial currents enter each of the network sections through the resistors R_{IC}. The net diffusion of these neutrons into other volume elements of the reactor is simulated by the currents in the R_ϕ resistors. Neutron processes such as absorption and slowing down, which are proportional to the neutron flux, are simulated by currents in the resistors R_a, R_q and R_u. These currents are proportional to the junction-point potential, which simulates the average neutron flux in the associated reactor element.

By successive adjustments of resistors and currents for each of the neutron groups, the operator follows an entire "generation" of neutrons through its life cycle, determining by direct measurement the fate of each neutron and, hence, the criticality condition of the reactor. The accuracy of the flux and criticality values so obtained depends on the input nuclear data, on the accuracy with which these data can be simulated by resistor settings, and on the electrical measurements made on the simulator network in extracting the problem solution.

The simulator design required that the accuracy of the solution be limited only by the accuracy of available nuclear data. All simulator adjustments and measurements, therefore, were required to be within 1% of the intended values. Neutron cross sections used as input data usually cannot be depended on for better than 5% accuracy.

Simulator Equations

The simulator is based on the unidimensional multigroup approximation of the age equation for neutrons in a reactor. The multigroup equations are of the form

$$-\frac{1}{3\Sigma_{tr_n}}\nabla^2\phi_n + \Sigma_{a_n}\phi_n + \frac{f_n\xi_n\Sigma_{t_n}}{U_n}\phi_n = \frac{f_{n-1}\xi_{n-1}\Sigma_{t_{n-1}}}{U_{n-1}}\phi_{n-1} + S_n \quad (1)$$

Where $n = 1, 2, 3, \ldots, N$. The quantities (3, 4) Σ_{tr_n}, Σ_{a_n}, and $(f_n\xi_n\Sigma_{t_n}/U_n)$ are the cross sections of the reactor materials for transport, absorption and slowing down, respectively, for the nth group of neutrons; ϕ_n is the neutron flux for the nth group; and S_n is the trial source of fission neutrons born in the nth group. For the first group of neutrons ($n = 1$), the quantity f_{n-1} equals zero; for the group of thermal neutrons, f_n equals zero. For other neutron groups, f_n is the ratio that the neutron slowing-down density at the low-energy end of the group, q_n^-, bears to the group's average slowing-down density, $q_{n_{AVG}}$.

An initial trial value of f_n is ordinarily assigned and then is adjusted by the method outlined in the section on simulator operation. The quantity Σ_{t_n} is the total cross section for neutrons of the nth group; ξ_n and U_n are, respectively, the average loss in the logarithm of the neutron energy in a collision and the interval in the logarithm of the neutron energy for the nth group.

To form the finite difference equations corresponding to Eq. 1, the derivatives indicated by the Laplacian operator are replaced by finite differences. The Laplacian of the neutron flux for a unidimensional problem is

$$\nabla^2\phi = \frac{1}{r^m}\frac{d}{dr}\left(r^m\frac{d\phi}{dr}\right) = \frac{1}{r^m}\frac{d(I)}{dr} \quad (2)$$

The value chosen for m is 0, 1 or 2, depending on whether the coordinate system is rectangular, cylindrical or spherical. The term I is a convenient contraction defined in Eq. 2. If the distance between points where ϕ is measured is chosen to be h, the necessary approximations are

$$d\phi/dr \approx (1/h)\left[\phi\left(r+\frac{1}{2}h\right) - \phi\left(r-\frac{1}{2}h\right)\right] \quad (3)$$

$$dI/dr \approx (1/h)\left[I\left(r+\frac{1}{2}h\right) - I\left(r-\frac{1}{2}h\right)\right] \quad (4)$$

With the approximations in Eqs. 3 and 4, Eq. 2 transforms to

$$(\nabla^2\phi_n)_r = \left(\frac{1}{r^m}\frac{dI}{dr}\right)_r \approx \frac{1}{h^2r^m}\left[r^m + \frac{m(m-1)r^{m-2}h^2}{8}\right][\phi_n(r+h) + \phi_n(r-h) - 2\phi_n(r)] + \frac{1}{h^2r^m}\left[mr^{m-1}\frac{h}{2}(\phi_n(r+h) - \phi_n(r-h))\right] \quad (5)$$

and the multigroup Eq. 1 becomes

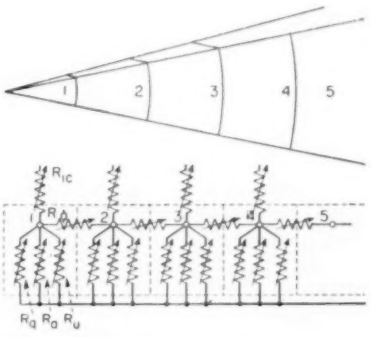


FIG. 1. Simplified diagram of reactor segment and simulator

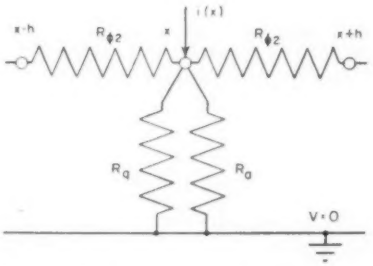


FIG. 2. Portion of electrical network

The Glenn L. Martin Company may soon supplement conventional analog and digital computing equipment (REAC and IBM systems) with a reactor simulator like that described here.

$$-\frac{1}{3\Sigma_{tr_n}h^2}\left[1+\frac{m(m-1)}{2}\left(\frac{h}{2r}\right)^2\right][\phi_n(r+h)+\phi_n(r-h)-2\phi_n(r)]-\frac{1}{3\Sigma_{tr_n}h^2}\left[\frac{mh}{2r}(\phi_n(r+h)-\phi_n(r-h))\right]+\Sigma_{a_n}\phi_n(r)+\frac{f_n\xi_n\Sigma_{t_n}}{U_n}\phi_n(r)=\frac{f_{n-1}\xi_{n-1}\Sigma_{t_{n-1}}}{U_{n-1}}\phi_{n-1}(r)+S_n(r) \quad (6)$$

This equation, a neutron balance equation for a unit volume element in a reactor, is very much like that describing the potential V at various junction points on the linear electric network, part of which is shown in Fig. 2. The junction points of the network, located at positions x, $x+h$, etc., are connected in series by the resistors R_ϕ and are connected to ground or zero potential by the resistors R_a and R_q. A current $i(x)$ can be forced into each junction point. Application of Kirchhoff's law to the currents i entering the junction point at a distance x from one end, yields

$$\frac{V(x-h)-V(x)}{R_{\phi_1}}+\frac{V(x+h)-V(x)}{R_{\phi_2}}+i(x)-\frac{V(x)}{R_q}-\frac{V(x)}{R_a}=0 \quad (7)$$

where $V(x)$ is the electric potential measured on the junction point at x.

If R_{ϕ_1} and R_{ϕ_2} vary according to the relations

$$R_{\phi_1}=R_0\Big/\left(x-\frac{1}{2}h\right)^m$$

and

$$R_{\phi_2}=R_0\Big/\left(x+\frac{1}{2}h\right)^m \quad (8)$$

where $m=0, 1, 2$, Eq. 7 becomes

$$-\frac{x^m}{R_0}\left[1+\frac{m(m-1)}{2}\left(\frac{h}{2x}\right)^2\right][V(x+h)+V(x-h)-2V(x)]-\frac{x^m}{R_0}\left[\frac{mh}{2x}(V(x+h)-V(x-h))\right]+\frac{V(x)}{R_q}+\frac{V(x)}{R_a}=i(x) \quad (9)$$

Equation 6 becomes equivalent to Eq. 9 if it is multiplied by $\omega r^m h$, the approximate volume of a reactor element of extent h at the point r

$$-\frac{\omega r^m}{3\Sigma_{tr_n}h}\left[1+\frac{m(m-1)}{2}\left(\frac{h}{2r}\right)^2\right][\phi_n(r+h)+\phi_n(r-h)-2\phi_n(r)]-\frac{\omega r^m}{3\Sigma_{tr_n}h}\left[\frac{mh}{2r}(\phi_n(r+h)-\phi_n(r-h))\right]+\omega r^m h\Sigma_{a_n}\phi_n(r)+\frac{\omega r^m h f_n\xi_n\Sigma_{t_n}\phi_n(r)}{U_n}=\frac{\omega r^m h f_{n-1}\xi_{n-1}\Sigma_{t_{n-1}}}{U_{n-1}}\phi_{n-1}(r)+\omega r^m h S_n(r) \quad (10)$$

Comparison of Eqs. 9 and 10 shows that the electric network sections are equivalent to reactor volume elements and that neutron fluxes may be equated to electric potentials at network junction points. It also shows that nuclear processes per unit time in a reactor volume element may be equated to current through the resistor simulating that process. The conditions required for this equivalence are

$$R_{tr_n}=3\Sigma_{tr_n}h/\omega \quad (11)$$

$$R_{a_n}=1/(\omega r^m h\Sigma_{a_n}) \quad (12)$$

$$R_{q_n}=U_n/(\omega r^m h f_n\xi_n\Sigma_{t_n}) \quad (13)$$

$$i_n(x)=(\omega r^m h f_{n-1}\xi_{n-1}\Sigma_{t_{n-1}}/U_{n-1})\phi_{n-1}(r)+\phi_{n-1}(r)+\omega r^m h S_n(r) \quad (14)$$

For convenience in operation of the simulator, two quantities remain arbitrary in Eqs. 10–14: First, choice of the reactor segment size factor ω permits the use of a range of resistor values given by Eqs. 11–13 that is within the available range. Second, proper choice of the total fission neutron source, on which the values $S_n(r)$ are dependent, leads to simulator currents that can be adjusted and measured conveniently.

Boundary conditions for interfaces between reactor zones are resolved inherently by the simulator network. The requirements of continuity of neutron flux and of neutron diffusion current are immediately satisfied by the continuity of electric potential and current at the boundary between any two network sections as in Fig. 1.

Electrical measurements on the network can be interpreted as solutions of the multigroup equations. The potential at each junction point of the network is the neutron flux within the corresponding volume element in the reactor. The current through any resistor is the number of neutrons/sec leaving the corresponding group and volume element through the mechanism simulated by that resistor.

For many reactor configurations having passive regions for reflectors or experimental facilities the two-group approximation can be further simplified by using lumped diffusion properties for these zones (*5*). On the simulator, this involves replacing the network ordinarily assigned to the passive zone by a single resistor or by a combination of resistor and current source.

Simulator Components

The resistance network of the simulator constructed at Lewis Laboratory consists of Helipot resistors requiring ten turns of a dial to traverse the entire available resistance range. These resistors, having a linearity of 0.1%, provide a useful range of resistance within the desired range of accuracy. Special selection of these resistors will also provide the required accuracy of 1% in total resistance.

The simplified schematic diagram of the simulator in Fig. 1 shows the arrangement of the various resistors that can be employed in the network. The network consists of 20 junction points interconnected by diffusion resistors, R_ϕ, and supplied by current from a 24-volt battery. The amount of this current entering each junction point is ordinarily adjusted to some prescribed value. Each section of the network also contains three resistors R_q, R_a, and R_s that connect directly to ground.

These resistors provide for three independently variable mechanisms for loss of neutrons—by absorption in various materials; slowing, inelastic scattering, diffusion in a second dimension; and by other applicable processes. The independent control provided for some of these resistors allows them to be varied exclusively to achieve special effects.

Each network resistor position shown in Fig. 1 holds two resistor plug-in units, with a switch for choosing the one to be connected. This feature permits rapid resistor changes required

in iterative solutions of two-group problems. It also extends the ranges of resistors available in certain positions for multigroup solutions.

The system used to measure fluxes and currents in the network appears in simplified form together with a more detailed diagram of an individual section of the simulator in Fig. 3.

The individual Helipot resistor units each contain a fixed series resistance. Thus, measurements of current through the unit can be made by simple measurements of the potential drop across the fixed resistors. A calibrated Helipot-type resistor, H, fitted with a large dial, operates as a potentiometer device to provide a balance for the potential to be measured on the network. The two potentials are compared by a balancing amplifier, B, which drives a motor, M, in a direction to balance the potentials and to measure them on the large dial.

This null-indicating system has the advantages of not loading the resistance network, of being insensitive to fluctuations in power supply potential, and of giving an easy-to-read indication of potential and current. A simple switching system permits rapid choice and measurement of any potential or current on the network. Moreover, because of the nature of the circuit, the results of simulator calculations are easily reproducible.

Simulator Operation

The simulator calculation program, in treating the multigroup equations individually, follows the same general steps employed in numerical solutions. The following steps outline the procedure used to solve the multigroup equation for each group of neutrons.

1. Set the network resistors according to the formulas given in Eqs. 11-14.

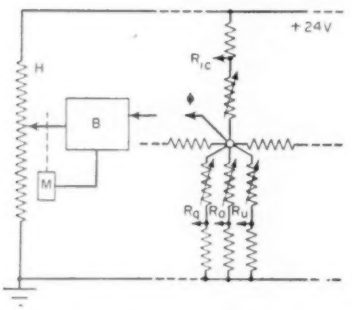


FIG. 3. Simplified diagram of measurement system and individual network section

The range of resistor values available for the network permits a convenient specification of the arbitrary factor ω appearing in these formulas.

2. A trial source of fission neutrons is specified as a function of position r. It is divided among the various groups according to the known fission spectrum. The magnitude of this source is chosen to make the operation of the simulator convenient.

3. The currents forced into the network junction points are adjusted so as to equal the neutron sources in the volume elements represented by those points. For the first group of fast neutrons, this generally consists of only fission neutrons. For other groups, it may include also slowing sources from higher energy groups.

4. The network will now indicate the distribution of neutrons in the group being considered. The potential measurements at the junction points give flux values and the resistor current measurements yield the rates of absorption, slowing, and so forth, in each volume element of the reactor.

5. For convenience, the currents forced into the network for any group can be multiplied by some arbitrary factor. The measured quantities, divided by this factor, then give the proper neutron fluxes and currents for the group.

6a. Insertion of the measured neutron slowing-down currents q_n^+, together with values for $q_{n_{avg}}$ in the relation $q_n^+ = f_n q_{n_{avg}}$, determines whether or not the value of f_n was properly chosen. Any change indicated by the equation requires that the slowing resistors be changed by a corresponding fraction. The group solution is repeated until a consistent value of f_n is found.

6b. An alternative scheme, one that can be used in place of the iterative procedure in step 6a, employs the linear average

$$q_{n_{avg}} = \frac{1}{2}(q_n^+ + q_{n-1}^+)$$

in Eq. 1, giving

$$-(\tfrac{1}{3}\Sigma_{tr_n}\nabla^2\phi_n + \Sigma_{s_n}\phi_n + 2q_{n_{avg}} = 2q_{n-1}^+ + S \quad (15)$$

This is equivalent to setting $f_n = 2$ and, in addition, to doubling the slowing source of neutrons for each net point. This additional contribution to the source at each point is then subtracted from the current that is measured through the corresponding slowing resistor, to give the approximate slowing down current.

A parabolic averaging process can also be employed. But this adds to the labor involved in the solution and does not correct for the solution's mathematical instability—a condition sometimes encountered near boundaries when the linear averaging process is used.

7. The measured slowing currents from a group are combined with fission source contributions to the following group—the entire process then being repeated for that following group. This process is repeated through the thermal group of neutrons, from which there is no slowing current.

8. The absorption currents for each group, when multiplied by the appropriate multiplication constant for that group, give the contribution to the fission source of the second generation of neutrons. The contributions of all groups give a new source of fission neutrons that can be compared with the original assumed fission neutron source. If the two sources are identical, the reactor assembly is critical, and the solution obtained is the steady-state solution desired.

9. Deviations in the assumed and derived sources indicate the need for readjustments and a second iteration of the solution. These values can also be interpreted to give an approximate figure for the excess reactivity of the reactor assembly.

Summary

The NACA nuclear reactor simulator gives reliable unidimensional solutions for the neutron flux and criticality conditions in a reactor. The accuracy of these solutions is generally limited by that of the input nuclear data and by the approximations of the multigroup calculation method. Flexibility of the simulator network makes it suitable for a variety of general reactor design studies, while direct simulation of neutron processes permits a detailed observation and variation of these processes.

BIBLIOGRAPHY

1. H. Hurwitz, Jr., Mathematical methods in pile calculations, AECD-3019 (1950)
2. Space simulator, AECD-2298 (1948)
3. Nuclear data for low-power research reactors, TID-235 (1950)
4. Neutron cross sections, AECU-2040 (1952)
5. D. Fieno, H. Schneider, R. B. Spooner, NUCLEONICS **11**, No. 8, 16 (1953)

How to use

Gas Evolution for Dosimetry of High Gamma, Neutron Fluxes

By EDWIN J. HART and
SHEFFIELD GORDON
Chemistry Division, Argonne National Laboratory
Lemont, Illinois

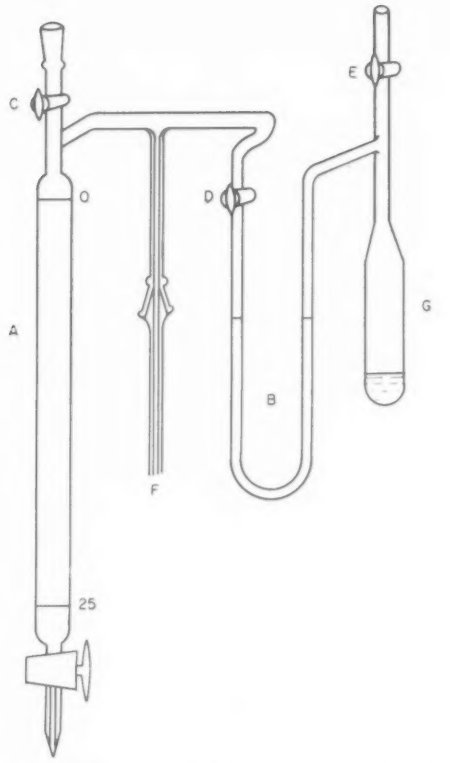


FIG. 1. Manometer system for measuring gas evolution

Reactor power and the integrated gamma and thermal-neutron fluxes can be monitored with the manometric method described. Gas yields for boric acid-potassium iodide solutions were determined for a Co^{60} source and for the CP-3′ thermal column

CHEMICAL DOSIMETRY has been advantageously applied to the measurement of X-ray and γ-ray dosages for a number of years (*1–3*). The principal drawback of this method of dosimetry in the past has been that chemical systems are not very sensitive to radiation. For low-level sources of ionizing radiation, chemical systems cannot compete with electronic detectors. However, with the advent of new powerful γ-ray and neutron sources, the problem is to find chemical systems of low sensitivity and long life that are specific to the different types of radiation.

A preliminary series of experiments has been carried out to determine the applicability of aqueous solutions to the measurement of high-level γ-ray and neutron sources and in particular to the radiations in CP-3′. In essence, water is decomposed by these radiations, and the hydrogen and oxygen evolved are measured at constant pressure in a gas manometer system. The general conclusion drawn from these studies is that gas-evolution measurements from aqueous solutions offer an excellent means for continuous monitoring of γ-ray and neutron fluxes in water-cooled reactors with neutron fluxes in the range from 10^{11} to 10^{15} n/cm²/sec.

The decomposition of water has been studied by many investigators, and, owing largely to the experiments of Allen and co-workers (*4*), a consistent explanation has been deduced to explain the effects of the various kinds of radiations. When irradiated to a steady-state decomposition, water yields two molecules of hydrogen to one of oxygen. The primary decomposition products are hydrogen and hydrogen peroxide, but the latter breaks down as a result of further action of the radiation into water plus

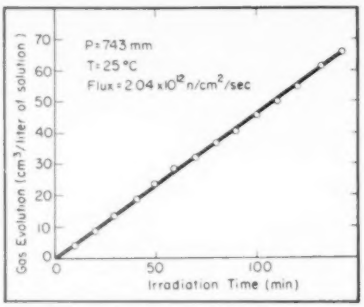


FIG. 2. Water decomposition in 0.1 mM potassium iodide solution

oxygen. The gas evolution for the general case is given by

$$(dN/dt) = \Sigma G_i\, dE_i/dt \qquad (1)$$

where N is the total number of molecules of oxygen plus hydrogen formed, G_i is the number of molecules of oxygen plus hydrogen formed by the ith type of radiation or reaction per 100 ev of energy absorbed in the solution by this process, E_i is the energy in units of 100 ev liberated by the ith process, and t is the time in seconds.

Equation 1 is simple and extremely useful in its application to pure γ-ray or thermal-neutron dosimetry. It must be pointed out, however, that this equation is applicable only under conditions where the water decomposition effects of the radiations are additive. This problem is discussed later. If it is assumed that Eq. 1 is applicable, one need only know the values of the constants G_i for γ-rays and for the particular neutron reaction used. In the case of the neutron reaction, the corresponding rate of liberation of energy term contains the neutron flux as a variable. Thus, flux can be calculated from rate of gas evolution and G_n.

Experimental Procedure

The gas-evolution measuring system used for γ-ray and pile experiments is shown in Fig. 1. Dibutyl phthalate is used in burette A and manometer tube B. Initially burette A is filled to the 0.0-ml mark, and stopcocks C, D, and E are opened. The cell containing the aqueous solution is attached to the system at F. In the case of γ-ray irradiations, a glass-to-glass seal is made at F. In the pile irradiations, a 25-ft length of 28 aluminum capillary tubing ⅛ in. o.d. and 1/16 in. i.d. is attached with a rubber connection at F.

The system is tested for leaks by increasing the internal pressure until about 25-cm pressure is indicated on the dibutyl phthalate manometer. When a leak was present, it could normally be detected in a few minutes by a drop in the level of the fluid; otherwise no change in level occurred after several hours' standing.

Cell G is a 10 to 15-ml tube containing water and is used to compensate in part for the volume changes caused by variations in temperature. In the γ-ray experiments, G and the solution irradiated are at room temperature. However, in the pile irradiation experiments, the temperature in the pile is more constant than room temperature, and the use of water in G is unnecessary. In pile irradiations, the room temperature fluctuation is less than 0.5° C during the time when the rate of gas evolution is measured.

The experiment described is designed to measure steady-state rates of gas evolution. Consequently, the initial readings are unimportant. During this initial period of time the solution becomes saturated with hydrogen and oxygen and develops a steady-state concentration of hydrogen peroxide. After the system has come to temperature equilibrium, stopcocks C and E are closed, and stopcock D is left open. As gas is evolved, the pressure change registers on the manometer and is equalized by opening the stopcock on the burette and draining out dibutyl phthalate until the original pressure is restored. By frequent withdrawals of phthalate, the rate of gas evolution at constant pressure is measured.

Results

Before applying the gas-evolution technique to the CP-3′ radiations, G_γ and G_n were determined for Co^{60} γ-rays and for the neutrons of the reactor thermal column, respectively.

Measurement of G_γ for Co^{60} γ-rays. The value for G_γ was measured in a

TABLE 1—Ferrous Sulfate Dosimetry of CP-3′*

Vertical thimble number	*Time of irradiation (sec)*	*Rate of Fe^{+++} production ($\mu N/min$)*	*Calculated energy absorbed (ev/l-min)†*
Central	30	1,032	$40. \times 10^{20}$
2	60	306	11.9×10^{20}
4	60	280.6	10.9×10^{20}
5	60	554	21.5×10^{20}

* Pile power 275 kw.
† Calculated on basis of 15.5 Fe^{+++}/100 ev. Chemical change is attributed to γ-rays.

TABLE 2—Gas-Evolution Data for Gamma and Neutron Reactions

Type reaction Type rays	γ-ray Co^{60}	$B^{10}(n, \alpha)Li^7$ Neutrons (thermal column)	$B^{10}(n, \alpha)Li^7$ Neutrons (thermal column)	$Li^6(n, \alpha)H^3$* Neutrons (thermal column)
Vol. solution (cm^3)	91.8	186.1	164.8	179.2
Conc. boric acid (M)	0.0	0.05	0.05	
Conc. KI (mM)	1.0	1.0	1.0	1.0
Gas production (cm^3/hr)	0.346	2.53	2.19	1.86
Temperature (°K)	295.6	298.5	296.8	297
Pressure (mm Hg)	736	744.5	743.5	733
Gas production (molecules/l-hr)	1.013×10^{20}	3.25×10^{20}†	3.19×10^{20}†	2.47×10^{20}†
Energy absorbed (ev/l-hr)	1.76×10^{22}	1.60×10^{22}	1.60×10^{22}	1.60×10^{22}
$G_{\text{total gas}}$	0.575	2.03	1.99	1.54
G_{H_2}	0.383	1.35	1.33	1.03
G_{O_2}	0.192	0.68	0.66	0.51

* 0.1040 M Li_2SO_4.
† Corrected for γ-flux existing in the thermal column.

1.0 mM potassium iodide solution using a 400-curie Co^{60} γ-ray source. A solution with a volume of 91.8 ml was irradiated, and the steady gas evolution measured in the time range of 70–115 hr. The rate found was 0.346 cm^3 gas/hr. The rate of energy absorption was measured using the ferrous sulfate dosimeter. With Hochanadel's $G_{Fe^{+++}}$ of 15.5 (*5*), 176.0×10^{20} ev were absorbed/l-hr. From the rate of gas evolution and the rate of energy absorption, G_γ for Co^{60} γ-rays equals 0.575. Several previous runs with smaller cells gave values of 0.55. The value of 0.575 is, however, believed to be more precise since the geometry in the irradiation chamber is more reproducible with the larger cells.

Decomposition of water in CP-3′. Pure triply distilled water undergoes substantially no decomposition in CP-3′. These results were obtained in short irradiations of a few minutes duration on air-free water. This work showed that there was a rapid development of a steady state of 10^{-5} M hydrogen and hydrogen peroxide. Further decomposition was not found.

To determine whether or not decomposition would occur in air-saturated solutions of triply distilled water, 55.3 gm of water were irradiated in the central thimble at a thermal flux of 3.22×10^{12} n/cm^2/sec for 6 hr. Possible gas evolution was followed by the manometer technique described above. No detectable gas evolution occurred over this 6-hr interval. This was as expected in view of the reported result that water irradiated in the central thimble of CP-3′ can resist decomposition even when poisoned with concentrations up to 20 mM in boric acid (*6*).

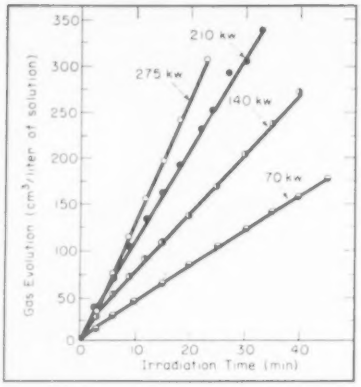


FIG. 3. Water decomposition in 0.1 M boric acid-0.1 mM potassium iodide solution in vertical thimble No. 5 of CP-3′

Measurement of γ-ray flux in CP-3′. Two methods have been employed for this measurement. One method is based on the radiation-induced oxidation of ferrous sulfate, in which case the rate of formation of ferric ion is measured. Owing to the limited solubility of air in water, this method can be used for low γ-ray fluxes or in very short irradiations at dosage rates prevailing in CP-3′. The pertinent data appear in Table 1.

The second method is based on the decomposition of water in 0.1 or 1.0 mM potassium iodide solutions. The data given in Fig. 2 are for a 62.9-gm solution of 0.1 mM potassium iodide irradiated for 4 hr to steady-state gas evolution in CP-3′. Vertical thimble No. 5 was used at a nominal thermal-neutron flux of 2.04×10^{12} n/cm^2 sec. After 4 min, gas evolution was linear with time, and steady-state conditions prevailed. Under these conditions it is found that 0.41 cm^3 (NTP) gas is evolved/l-min. This amount of gas is produced by the decomposition reaction in water since the potassium iodide is added to prevent the back reaction (*7*).

It is concluded from the data of Fig. 2 that the major portion (probably over 90%) of the energy absorbed in the vertical thimbles is γ-ray energy. This is apparent from a calculation of energy absorption using Eq. 1 for γ-rays

$$\frac{dE}{dt} = \frac{1}{G_\gamma}\frac{dN}{dt} = 1.74\frac{dN}{dt} \qquad (2)$$

Since dN/dt equals 1.10×10^{19} molecules/l-min, dE/dt equals $1.91 \times 10^{19} \times 10^2 = 19.1 \times 10^{20}$ ev/l-min for VT No. 5 at a power level of 275 kw. This is to be compared with the ferrous sulfate value of 21.5×10^{20} ev/l-min given in Table 1. This 12% difference is not surprising since the time of irradiation of the ferrous sulfate solutions was only 60 sec. Heavy-particle radiation, such as recoil protons from fast-neutron collisions, would tend to increase the value of the gas yield relative to the Fe^{+++} yield. If one assumes that the error of measurement is of the order of 5% or less, then the results may indicate that the Co^{60} γ-ray G_γ value is slightly too large for the more energetic pile radiations. G_γ values on higher-energy γ-rays are required to answer this question. In the present article, it will be assumed that G_γ values for Co^{60} γ-rays and pile radiations in the vertical thimble of CP-3′ are identical.

Measurement of G_n for $B^{10}(n, \alpha)Li^7$. The G_n for this reaction was measured in the thermal column of CP-3′ in two separate experiments, each employing about 180 ml of 1.0 mM potassium iodide plus 50 mM boric acid solution. The essential gas evolution data, given in Table 2, show that, at the prevailing flux in this section of the thermal column, 13.6 cm^3 gas/l-hr were produced.

The integrated γ-ray and thermal-

TABLE 3 Gas-Evolution Data for Aqueous Solutions in CP-3′*

Column number	*1*	*2*	*3*	*4*	*5*	*6*
Vertical thimble number	2	4	2	4	2	5
Concentration of KI (mM)	0.1	0.1			0.1	0.1
Concentration of H_3BO_3 (mM)	50.0	100.0	50.0	100.0	100.0	100.0
Weight of sample (gm)	68.5	65.2	67.8	67.9	65.1	66.1
Gas production (cm^3/min)	0.231	0.381	0.1345	0.314	0.391	0.742
Gas production (cm^3/l-min)	3.37	5.83	1.98	4.62	6.44	12.25
Gas production (10^{19} molecules/l-min)	9.03	15.6	5.31	12.4	17.2	32.8
Gamma energy absorbed (10^{20} ev/l-min)	12.7	10.8	12.7	10.8	11.9	21.5
Gas from gammas (10^{19} molecules/l-min)†	0.7	0.6	0.7	0.6	0.7	1.2
Gas from B^{10} reaction (10^{19} molecules/l-min)	8.3	15.0	4.6	11.8	16.5	31.6
Calculated neutron flux (10^{12} n/cm^2/sec)	1.34	1.21			1.33	2.55
Neutron flux (10^{12} n/cm^2/sec) (*10*)	1.39	1.18	1.39	1.18	1.39	2.04

* Pile power 275 kw.
† $0.575 \times (dE/dt)$ γ-ray.

neutron flux prevailing in the irradiation cell was obtained by irradiating 1 mN ferrous sulfate in the presence and absence of 50 mM boric acid. The thermal-neutron flux was calculated using McDonnell's value of $G_{Fe^{+++}} = 4.3$ for the $B^{10}(n, \alpha)Li^7$ reaction in ferrous sulfate solution (*8*). E_r is assumed to be 2.34 Mev/B^{10} disintegration (*9*). The effect of the 0.478-Mev γ-ray on the decomposition of water has been neglected.

Neutron flux in vertical thimble of CP-3′. Since G_γ for Co^{60} γ-rays and G_n for the $B^{10}(n, \alpha)Li^7$ reaction have been measured, it is now feasible to measure γ-ray and thermal fluxes in reactors having relatively low epithermal neutron fluxes.

The results of several irradiations in the central thimble of CP-3′ are given in Table 3. The irradiations containing the potassium iodide in addition to the boric acid are the ones useful in measuring the neutron flux. In these irradiations, the potassium iodide prevents the recombination of hydrogen and hydrogen peroxide formed during irradiation. Under these conditions, the total gas evolved is a measure of the γ-ray plus the $B^{10}(n, \alpha)Li^7$ reactions.

Gas evolution due to γ-rays (plus epithermal neutrons) is 8% or less, depending on the concentration of boric acid used. By comparing the results of data appearing in columns 1 and 5 of Table 3, it is observed that dN/dt(molecules gas/l-min) is proportional to boric acid concentration.

The data of Table 3 show that the presence of the γ-ray flux has an appreciable effect in reducing gas evolution in boric acid solutions (compare columns 1 with 3, and 2 with 4). The presence of 0.1 mM potassium iodide has an enormous effect, increasing the yield of gases in water decomposition. Recombination of the decomposition products of water (H_2, H_2O_2, and O_2) in CP-3′ takes place through the interaction of the large γ-ray flux present in the reactor. Since this flux is constant and independent of boric acid concentration, its relative effect is most pronounced at low boric acid concentrations (*6*). In the absence of potassium iodide, therefore, gas evolution is not proportional to boric acid concentration, while yield is proportional to concentration in boric acid solutions containing potassium iodide.

From the data of Table 3, one can calculate the flux in the reactor using Eq. 1 and the G value given in Table 2 for total gas production from the $B^{10}(n, \alpha)Li^7$ reaction; that is

$$\left(\frac{dN}{dt}\right)_{\text{mol/l-sec}} = 2.01\left(\frac{dE_n}{dt}\right)_{\text{100 ev/l-sec}} \quad (3)$$

$(dE_n/dt)_{\text{100 ev/l-sec}}$ can be expressed in terms of known constants by

$$\left(\frac{dE_n}{dt}\right)_{\text{100 ev/l-sec}} = \frac{E_r}{100}\,\text{ev} \times f\sigma M(6.02 \times 10^{23}) = kf$$

Using the values $E_r = 2.34 \times 10^6$ ev, $\sigma = 7.37 \times 10^{-22}$ cm^2 (*11*), M = moles/l of boric acid, and f = flux in n/cm^2/sec, one calculates a value for k of

$$k = (2.34 \times 10^4)(7.37 \times 10^{-22})(6.02 \times 10^{23})M = 1.03 \times 10^7\, M$$

Therefore, from Eq. 3 one gets

$$\left(\frac{dN}{dt}\right)_{\text{mol/l-sec}} = 2.01kf = (2.07 \times 10^7)Mf$$

Table 3 gives the calculated fluxes f for various concentrations of boric acid.

Gas evolution as a measure of pile power. The effect of pile power on the rate of gas evolution was studied on a 0.1 mM potassium iodide plus 100 mM boric acid solution in vertical thimbles 2 and 5. Equilibrium rates of gas evolution were measured consecutively at 275, 210, 140, and 70 kw power. Figure 3 illustrates the manner in which the rate of gas evolution changes. In attaining an equilibrium rate at the highest power, about 30 min are required. However, subsequent equilibria are reached at lower powers in 5 to 20 min.

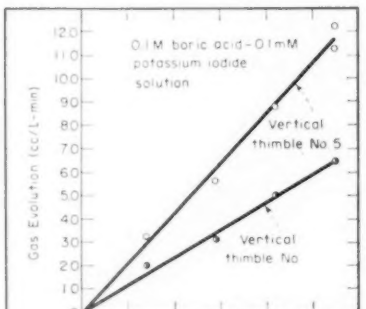


FIG. 4. Effect of pile power on water decomposition (lower curve refers to vertical thimble No. 2)

TABLE 4—Composition of Gas from Aqueous Solution

Irradiation source	*Solution*	H_2/O_2
Co^{60}	KI (air present)	2.70
Co^{60}	KI (Ne flushed)	2.16
CP-3′	KI, H_3BO_3	2.74
CP-3′	KI, H_3BO_3	2.70

Figure 4 shows that in vertical thimbles 2 and 5 gas evolution is linear with pile power and that the curve extrapolates to zero gas evolution at zero power.

Composition of gases. The gases liberated during γ-ray and pile irradiation consist of hydrogen and oxygen. Table 4 gives the results of several determinations. In general, an excess of hydrogen over the stoichiometric H_2/O_2 ratio of 2.0 is observed. This deviation is due to: (1) increased solubility of oxygen over hydrogen, and (2) the holding up of oxygen in hydrogen peroxide. Under equilibrium conditions, however, the ratio should approach 2 as a limit even under conditions of high hydrogen peroxide holdup.

Experimentally this ratio was nearly obtained in the case of Co^{60} γ-rays. However, under these conditions, hydrogen peroxide at steady-state concentration is about 0.3 mM.

Owing to the relatively large volume of gas space in the manometer and aluminum tubing used in the pile irradiations, extremely large volumes of gas generated from the aqueous solution would be required to flush out the initial high proportion of hydrogen gas formed. This is especially high in the case of boric acid solutions, where the equilibrium build-up of hydrogen peroxide is about 10 mM.

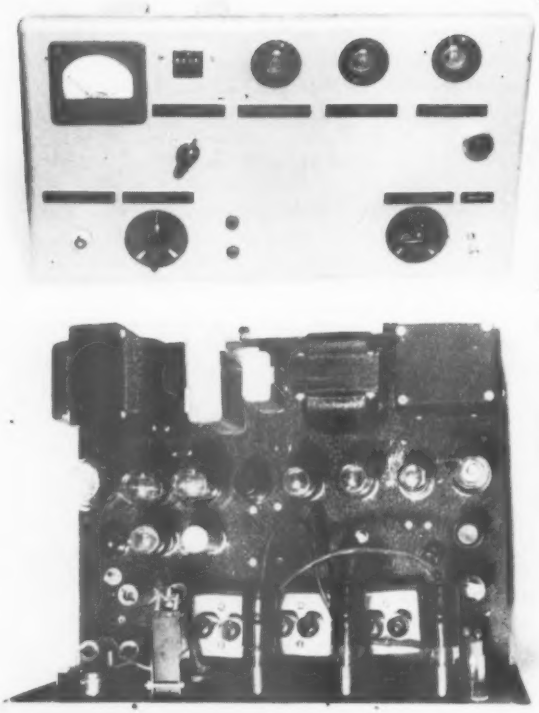
BIBLIOGRAPHY

1. H. Fricke, S. Morse, *Am. J. Roentgenol. Radium Therapy* **18,** 430 (1927)
2. H. Fricke, E. R. Brownscombe, *J. Am. Chem. Soc.* **55,** 2358 (1933)
3. N. Miller, *J. Chem. Phys.* **18,** 79 (1950)
4. A. O. Allen, C. J. Hochanadel, J. A. Ghormley, T. W. Davis, *J. Phys. Chem.* **56,** 575 (1952)
5. C. J. Hochanadel, *ibid.* **56,** 587 (1952)
6. E. J. Hart, S. Gordon, ANL-EJH-7 (1951); ANL-4717, section 2.2.4 (1952)
7. A. O. Allen, *J. Phys. & Colloid Chem.* **52,** 479 (1948)
8. W. R. McDonell, private communication
9. B. Petree, C. H. Johnson, D. W. Miller, *Phys. Rev.* **83,** 1148 (1951)
10. W. H. McCorkle, private communication
11. R. B. Sutton, B. D. McDaniel, E. E. Anderson, L. S. Lavatelli, *Phys. Rev.* **71,** 272 (1947)

These pulse requirements . . .

Tube	Type	Pulse input	Amplitude (volts)	Length (μsec)	Maximum frequency (cps)
Dekatron GC10B	Gas filled	Double, 120 deg out of phase	130	30–80	5,000
Dekatron GC10D	Gas filled	Single, triangular	130	25	16,000
Nomotron G10/241	Gas filled	Single, square	150	12	60,000
Philips E1T	Vacuum	Triangular	10	9–10 (1-μsec rise, 8-μsec fall)	100,000

. . . are met in these instruments ➔ by . . .



DEKATRON (Ericsson type GC-10B) scale-of-1,000

Reliable Scaling Circuits

By J. C. BAKER and G. G. EICHHOLZ
Mines Branch
Department of Mines and Technical Surveys
Ottawa, Canada

IN RECENT YEARS decade scaling circuits have gradually replaced binary stages in many applications where the advantages of decimal recording outweighed the initial complications in circuit design.

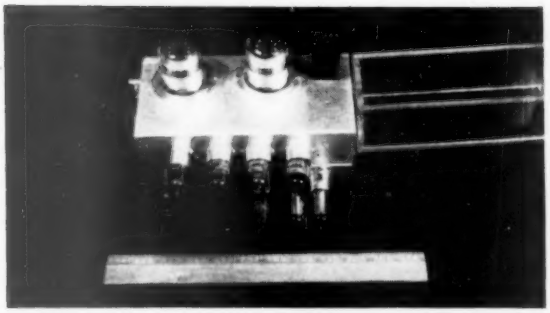
Such circuits are usually based on binary stages, arranged to give 16 − 6 or 8 + 2 counts (*1, 2*). The number of tubes required for this purpose has tended to make such decade circuits inherently less reliable and, of course, more bulky than binary stages. For this reason, the development of various self-contained decade counter tubes has provided an opportunity to develop reliable and compact decade scaling circuits in all those cases where long life, small bulk and a minimum of maintenance are important and where no extremely high counting rates are anticipated.

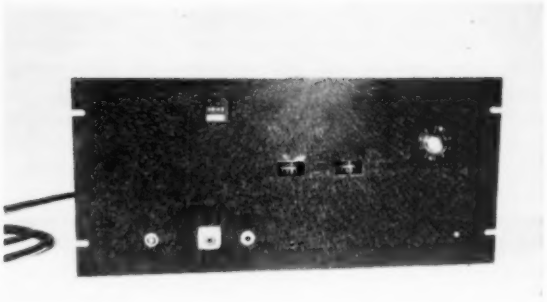
Although descriptions of the various types of tubes have been published (*3–11*), few attempts seem to have been made to evaluate their properties for use in scaling equipment and to present practical circuits. We are, therefore, mainly concerned here with the circuits required to operate those tubes that appear to be useful in radiation counting equipment where space, power consumption, maintenance and long life are factors of importance.

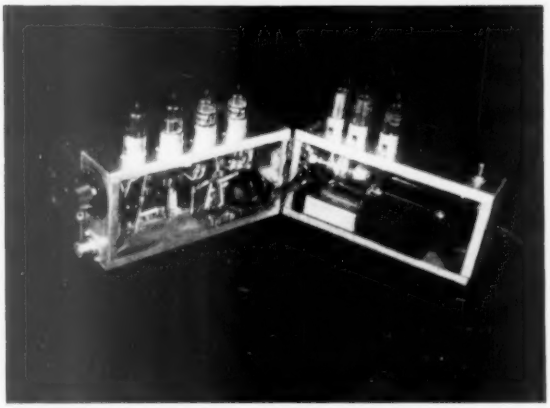
This report surveys the tubes available at present and compares the properties and characteristics of those that are on the market at a reasonable price and are of particular interest in nuclear work. Some circuits that have been developed for pulse counting are described, but no special attention is paid to those tubes and circuits that have their primary uses in computer circuits.

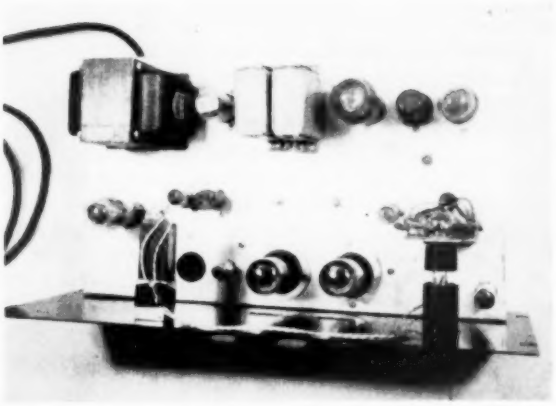
GAS-FILLED SCALING TUBES

Several cold-cathode, gas-filled counting tubes have been developed in recent years. Among these are the "Dekatron," made by Eriesson Telephone Co. (*3, 4*), the "Remtron," made by Remington-Rand (*5*), the "Nomotron," made by Standard Telephones & Cables Ltd. (*6*), and the Western Electric type 6167 (*7*). Of these, the Dekatron & Nomotron provide visible interpolation counts and are commercially available. Both tubes have been used in the Mines Branch laboratories in Ottawa. Several applications of Dekatrons to specific problems have been published recently (*8, 9*); only data of interest in the nuclear field is considered here.









NOMOTRON (Standard Telephones & Cables type G10/241) scale-of-100

EIT (Philips) scale-of-1,000

for Decade Tubes

The advantages of a cold-cathode tube are obvious: practically unlimited life, relative insensitiveness to voltage variations and temperature conditions, and compactness. On the other hand, the gas-ionization processes are relatively slow and impose an upper limit on the pulse-repetition rate they can handle. All decade scaling tubes require certain minimum pulse widths and amplitudes for proper operation; the provision of properly shaped pulses, as derived from the signal pulses of various radiation detectors, gives rise to some difficulties in circuit design. Further, the multiple electrode structure of the tubes results in high input capacities.

Dekatrons

Two types of Dekatrons have been developed: (1) double-pulse tubes (*3*), known as GC-10A and GC-10B; and (2) single-pulse tubes (*4*), GC-10D.

In the double-pulse tubes, a glow discharge is moved from one "cathode" to another by applying successively two pulses to each system of auxiliary electrodes, known as Guide 1 and Guide 2. At low counting rates and with regular spaced pulses this can be achieved with simple circuits, such as those in Figs. 1 and 2.

A circuit such as that shown in Fig. 1 can be used at pulse frequencies up to 1,100 cps and can be adapted for resetting. At higher counting rates and random amplitudes, a simple circuit such as that is no longer satisfactory, as the coupling capacitors tend to remain charged for varying times. For that reason it is preferable to use a preliminary pulse-generating circuit, e.g., a univibrator, to feed pulses of uniform amplitude and length to the guides. The development of such a circuit employing GC-10A tubes has been described in a previous report (*12*). That circuit worked at repetition rates up to 2,000 cps and is superior to a circuit published subsequently by Nilssen (*13*).

For faster counting. A faster circuit, working up to 2,500 cps, is of the type shown in Fig. 2. Here the input pulse is shaped in a univibrator, followed by a phase-splitting stage in which the time lag between the two driving pulses is created by differentiation in the circuits of a double triode biased to cut-off. The pulse transformation is indicated in Fig. 2.

For stable and reliable operation this circuit requires a well-filtered voltage supply, and, in particular, the negative bias lines must be stable, since the bias settings proved rather critical. Subsequent scaling stages can follow the simpler design of Fig. 1, if desired.

This circuit led to the design of a self-contained scaling unit incorporating three GC-10B tubes in a scale-of-1,000 (see picture on this page). This unit, developed for a recording radiation monitor in a mine installation,

handles random pulses from scintillation detectors. The photographs show the simple layout and compactness possible with dekatron tubes. The meter is part of a ratemeter included in the unit; for ease of servicing, the interstage pulsing circuits were embodied in plug-in subunits of identical construction using pairs of 12AU7 tubes (Fig. 3), even though a simpler pulse-transfer stage would have been adequate at the slower stages. This equipment has worked without trouble for nearly two years.

To handle the range in pulse amplitude and repetition rates required, one 6J6 univibrator is used as a discriminator and pulse shaper. The second 6J6 acts as a ratemeter. The 12AU7 driver units are required to provide two 100-volt pulses, 120 deg out of phase, for the two guides. The pulses have a fast rise time and a pulse length of 80 μsec. For decreased current drain, the 12AU7 tubes could be replaced by 12AX7 tubes with a higher plate load.

Biasing. The complication of these circuits arises from the use of the negative bias lines whose voltage is rather critical. Use of these bias voltage lines was recommended by the manufacturers and is required to ensure steady operation at pulse frequencies. However, a much simpler circuit results if the guides are returned to ground potential with the cathode self-biased. A circuit of this type has been employed in a commercial unit designed by Atomic Instrument Co. With a Schmitt trigger input circuit, such scalers will handle pulse amplitudes above 8 volts at rates up to 5 kc.

In view of the 30-μsec input pulse time required, higher counting rates are theoretically possible with the GC-10B and have been obtained with various more refined circuits, but these circuits are not yet established for reliable performance.

Driving stages. The next logical development is the replacement of the "hot" driver stages by cold-cathode tubes or transistors. This work has been pioneered mainly at Harwell, and lately at Chalk River, and is mentioned here for completeness only. A good example of this approach is Kandiah's circuit, mentioned by Taylor (*14*), in which all guide-2 electrodes are excited simultaneously. Several other circuits using British and Canadian cold-cathode trigger tubes are being developed in Britain and Canada.

The use of transistors in the driving stages has been tried, both at the Mines Branch and other laboratories. Owing to the high pulse amplitudes required, blocking oscillator circuits seem to offer the only possible approach. At the present stage of transistor development, such a circuit can be made to work but does not quite meet the requirements of reliability for immediate laboratory use. With the expected improvement in consistency and cheapness of junction transistors, such all-cold GC-10B scalers may be developed within a reasonable time.

Single-pulse Dekatron. A more recent development is the single-pulse Dekatron, known as GC-10D (*4*). This tube, which has been available in experimental quantities only so far, has a different electrode assembly from the GC-10B with 40 electrodes. This makes it possible to use a single transfer pulse instead of the two separate out-of-phase pulses needed for the earlier Dekatrons. This pulse must have a saw-tooth wave form or a greatly rounded square wave of pulse length of at least 25 μsec. Of the circuits tried, a 6J6 blocking oscillator circuit appeared to be the most satisfactory. Figure 4 shows the circuit used, which is capable of handling pulse rates up to 16,000 cps. To avoid changes in input guide bias, the use of clamping diodes is recommended. These diodes determine the required input amplitude—90 volts in the present case. Above repetition rates of 16 kc, the coupling condensers stay charged at the guide potential, and the effective input amplitude drops below threshold.

The requirement for a single trigger pulse makes the use of a cold-cathode trigger tube possible for interstage coupling. One such tube tried is the STC GI/370 K gas-filled trigger tube. The circuit is shown in Fig. 5. Other tubes, e.g., Mullard type VX8107, have been used successfully.

Life tests so far have indicated that the GC-10D seems to be far less reliable in its present form than the GC-10B. Further development may

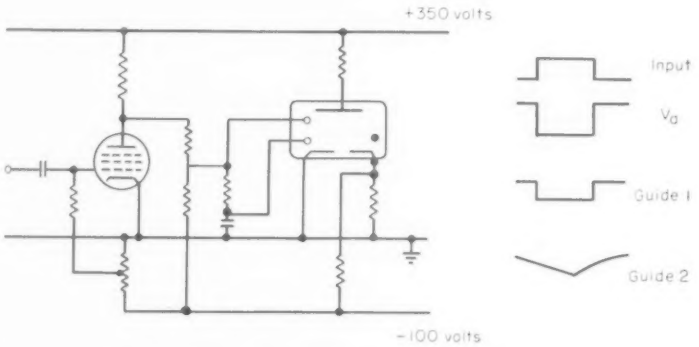


FIG. 1. Phase-splitting circuit and pulse shapes for GC-10A and GC-10B

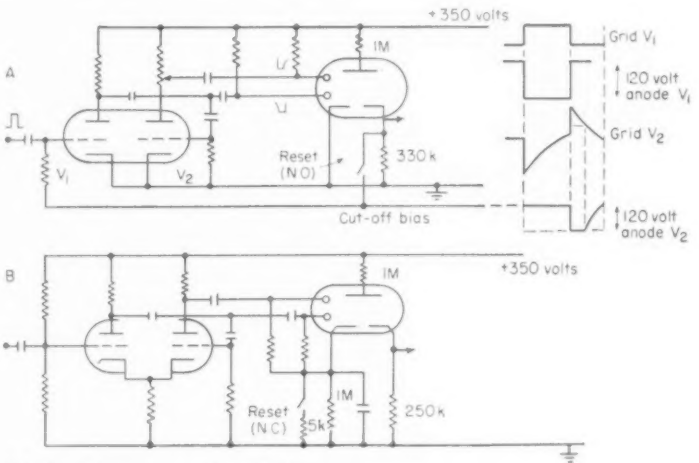


FIG. 2. Trigger circuits for GC-10B

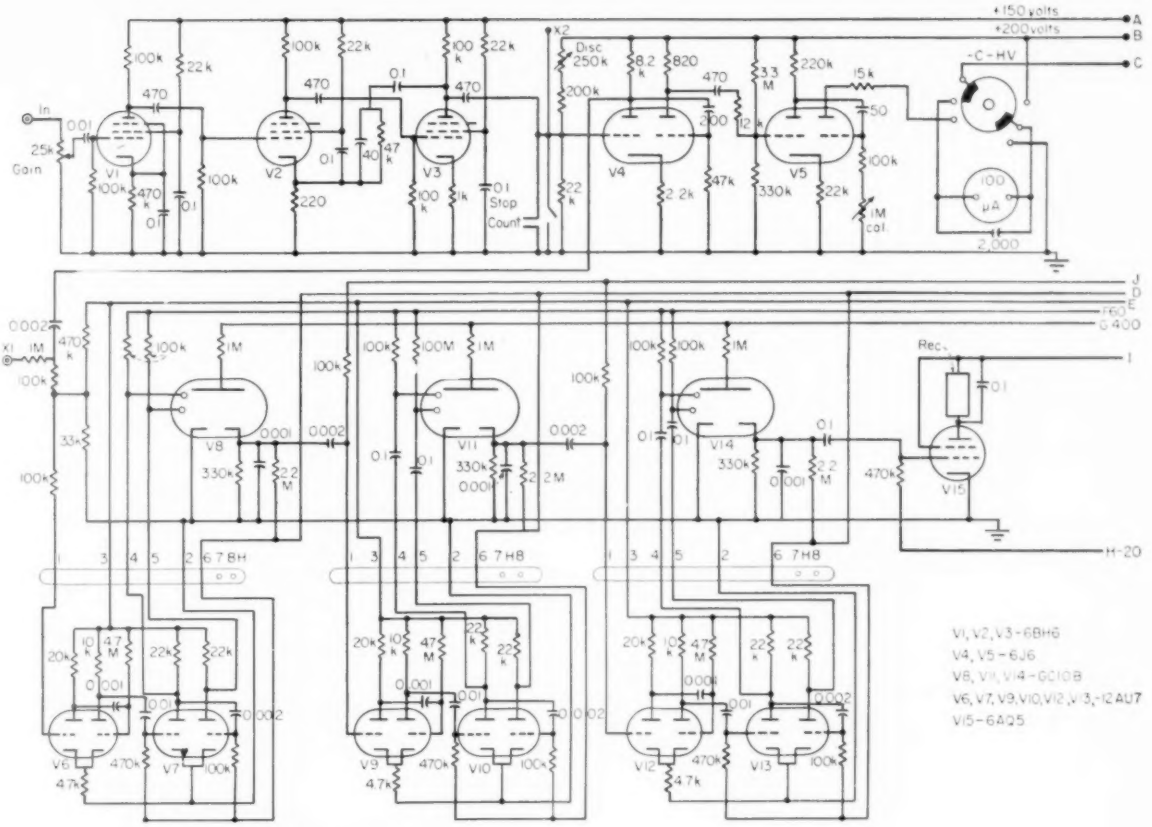


FIG. 3. Radiation monitor scale-of-1,000 and ratemeter

overcome that difficulty. However, as matters stand, the GC-10B appears to have found more favour generally despite the slightly greater complexity of its associated circuits. The extensive work done on these tubes has definitely established their usefulness and their superiority over standard feed-back circuits for low-count applications. This applies to practically all Geiger counters and many low-level detection applications.

Nomotrons

The Nomotron is a gas-filled scaling tube similar in conception to the Dekatron, though of different construction (*6, 10*).

In its original form, G10/240E, a top anode connection made direct reading awkward and connections difficult. However, a later version, G10/241 or CV2223, is much more convenient and mechanically sounder. This tube operates on transfer pulses of 140-volt amplitude, 8–16 μsec in length. The requirement of that tube for a specific pulse length presents a problem that was finally solved by the use of a 12AT7 univibrator in the circuit (Fig. 6). This circuit proved fairly insensitive to changes in high voltage and operates at frequencies up to 60 kc, close to its theoretical limit.

Indications so far are that the Nomotron may easily rival the Dekatron in performance. Its operation appears to be less critical, though it is believed that the closer tolerances required in manufacture may keep the cost above that of the Dekatrons.

An experimental self-contained Nomotron scale-of-100 is shown on p. 45. It is clear that the low current consumption of these cold-cathode tubes will indirectly result also in more compact powerpacks. With cold-cathode trigger tubes (*11*), battery operation may be quite feasible, a feature of value in mine assay work. However, the large pulse amplitude required makes the use of transistors less likely.

ELECTRON-BEAM SCALING TUBES

Several vacuum tubes have been described that contain internal electrodes for decimal or duodecimal scaling. Among these are the Philips scaling tube (*15*), the "Trochotron" (*16, 17*) and the Hollway tube (*18, 19*). Other tubes in this class are based on television cathode-ray scanning tubes. Of these, only the Philips tube is commercially available at present and has been used in laboratory equipment.

Electron-beam tubes are potentially very fast owing to the negligible inertia of the beam and the absence of ionization effects. An upper limit to accepted pulse rates is set primarily by the interelectrode capacities.

Philips Tube

In the Philips tube, type E1T, a beam of electrons is focussed on a slotted screen, which provides ten stable beam positions. Corresponding to each position there is a numbered spot on a fluorescent screen on the inside wall of the tube that lights up

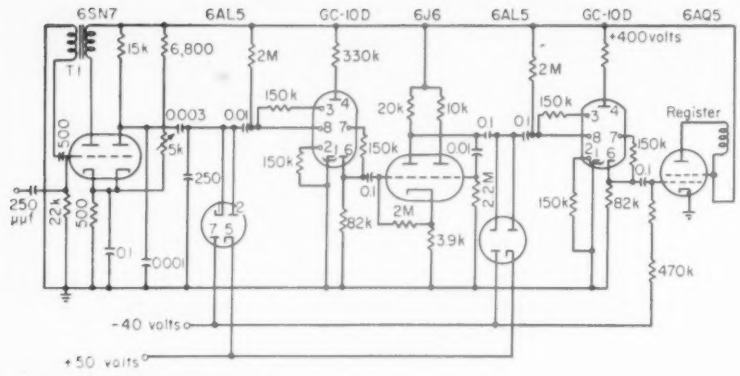


FIG. 4. GC-10D scaling circuit

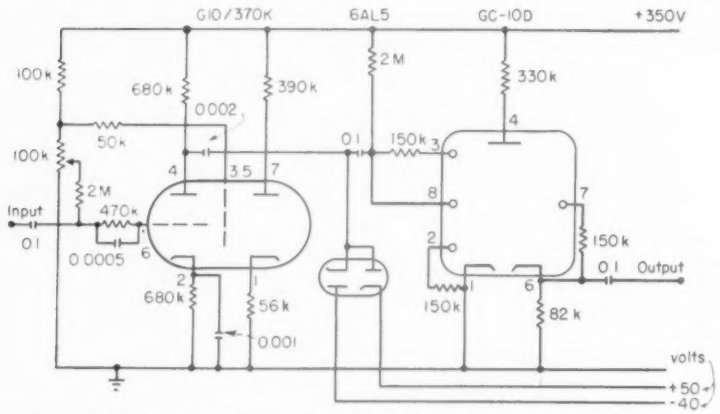


FIG. 5. Cold-cathode trigger circuit for GC-10D

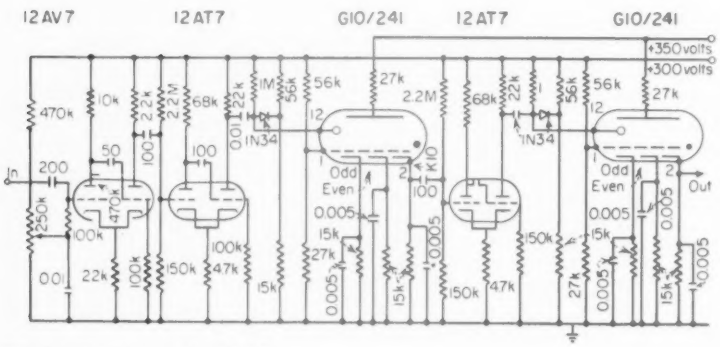


FIG. 6. Nomotron scale-of-100

when hit by the beam. In this way, direct indication of input counts is provided on the tube wall. As the beam sweeps across the slots, the anode current fluctuates and provides a particularly large pulse when it reaches the tenth position at the output electrode of the tube.

For proper operation, the relative voltages must be adjusted to their correct ratios. These voltage ratios are found to be more critical than the absolute voltage values, and in practice it was found best to keep one resistor in the voltage-divider chain variable to adjust the zero-deflection voltage on one of the deflector plates. The input pulses must be such as to provide just enough voltage variation to switch the beam into the next higher position. Consequently, the trigger circuit must supply pulses of constant amplitude, rise time and decay time over the whole range of repetition frequencies encountered. Quite high counting rates are possible, limited only by the interelectrode capacities. These must be charged and discharged for each applied pulse; the counting rate reaches its limit around 100,000 pulses per second in the E1T tubes tested, since the applied pulses needed a rise time of 1 μsec and a decay time of 8 μsec. At 100 kc, this leaves a 1-μsec interval between pulses.

High-speed circuit. The manufacturers' suggested input circuits proved reliable up to about 15 kc. Investigations showed, however, that a univibrator of the type recommended cannot possibly deliver the same pulse-voltage amplitude at 100 kc as at 10 kc, because the average anode current is increased and hence the average anode voltage decreased. As the voltage increment to the E1T must always be the same to give the same beam deflection, other circuits had to be developed.

The present circuit uses a 6D4 thyratron to discharge a capacitor through an inductance, producing one-half sine wave at its resonant frequency, the rest being damped by the conducting thyratron. The amplitude of the pulse is now determined principally by the Q factor of the inductance and not by the tube.

Figure 7 shows the circuit finally adopted in which the E1T part is similar to that recommended by the manufacturers, though several component values differ. These tubes require relatively small voltage increments to displace the electron beam over the set of numbers. Therefore, very precise regulation of the power supply and the use of precision resistors in the voltage divider network are required. With these precautions, reliable counting rates up to 100 kc were obtained.

It was found that the only way to set up these voltages was by means of an oscilloscope and pulse generator. The variable voltage control is then set to give ten equal steps on the waveform developed on pin 5, the anode of the E1T, as indicated in Fig. 8.

Scale-of-1,000. A scale-of-1,000 containing two E1T tubes is shown on p. 45. The E1T tubes work into a GC-10D whose output actuates a mechanical register through a power amplifier stage.

Again the simplicity of the lay-out and the small number of components

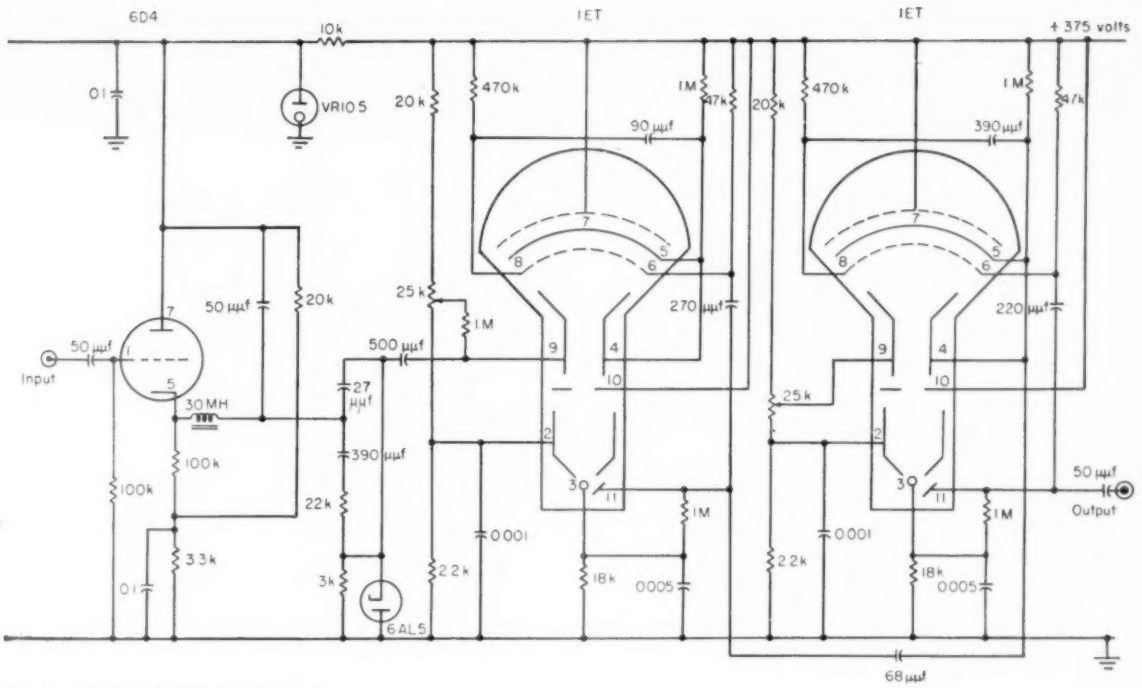


FIG. 7. Philips E1T tube scaler circuit

required are striking when compared with conventional scaling equipment. The coupling between E1T tubes is direct, with successive decreases in coupling capacitances in successive stages to give the correct attenuation. Conversely, the reset capacitors should be ten times that of the previous stage to hold the correct amount of charge.

The Philips E1T tube is thus the fastest available scaling tube. However, being a filamentary tube, its life is not as unlimited as that of the gas-filled tubes. Its circuit is more critical to adjust, but once set these tubes have been found to operate very satisfactorily over long periods.

A practical problem common to Philips tubes and Nomotrons is the need for a base-mounting duodecal tube socket. Commercial television tube sockets are not very convenient and have to be adapted laboriously for the purpose. However, there seems to be hope that a duodecal socket with fixed pins will become available shortly.

DISCUSSION

This work has been confined to three tube types only. Other scaling tubes like the Remtron, Trochotron and 6167 make no provision for display of interpolating positions and are more suited to computer applications. The same holds for those modifications of the Dekatron in which all the cathodes are brought out separately.

Consideration was also given to the use of ferroresonant magnetic scaling units (*20, 21*). However, preliminary work showed that little saving in tubes could be achieved when compared with conventional binary circuits, and their speed is no greater than that of decade-tube circuits. The main application of magnetic binary scalers appears to be, therefore, in the computer field, where their persistent memory may be useful.

Of the tubes investigated, it is clear that all should have wide applications in the low-speed nuclear counting field. The E1T tube is the fastest and most self-contained type. The Nomotron is the easiest to operate over a wide range of repetition frequencies. The Dekatron is the most advanced in production and availability and most likely to be used immediately in "all-cold" portable equipment.

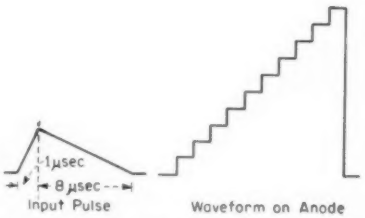


FIG. 8. E1T waveforms

* * *

This article is based on the Mines Branch Topical Report TR-113/53.

BIBLIOGRAPHY

1. W. C. Elmore, M. L. Sands, "Electronics" (McGraw-Hill Book Co., New York, 1949)
2. J. T. Potter, *Electronics* **17,** No. 6, 110 (1944)
3. R. C. Bacon, J. R. Pollard, *Electronic Eng.* **23,** 173 (1950)
4. J. R. Acton, *Electronic Eng.* **24,** 48 (1952)
5. J. J. Lamb, J. A. Brustman, *Electronics* **23,** No. 11, 92 (1949)
6. G. H. Hough, *Proc. Inst. Elec. Eng. (London)* **99,** part IV, 177 (1952)
7. D. S. Peck, *Elec. Eng.* **71,** 1136 (1952)
8. G. H. Hough, D. S. Ridler, *Elec. Commun.* **27,** 214 (1950)
9. J. McAuslan, K. J. Brimley, *Electronic Eng.* **24,** 408 (1952)
10. A. B. Thomas, *Proc. Inst. Radio Eng. (Australia)* **13,** 311 (1952)
11. G. H. Hough, D. S. Ridler, *Electronic Eng.* **24,** 272 (1952)
12. J. C. Baker, G. G. Eichholz, Mines Branch Topical Report, TR-89/51, Ottawa (1951)
13. I. Nilssen, *Trans. Chalmers Univ. Technol. Gothenburg,* No. 125 (1952)
14. D. Taylor, NUCLEONICS **11,** No. 3, 40 (1952)
15. J. L. H. Jonker, A. J. van Overbeck, P. H. de Beurs, *Philips Research Repts.* **7,** 81 (1952)
16. H. Alfven, H. Romanus, *Nature* **160,** 614 (1947)
17. H. Alfven, L. Lindberg, K. G. Malmfors, T. Wallmark, E. Astrom, *Trans. Royal. Inst. Technol. Stockholm,* No. 22 (1948)
18. D. L. Hollway, *Electronics* **25,** No. 5, 152 (1952)
19. D. L. Hollway, *Australian J. Phys.* **6,** 96 (1953)
20. A. Wang, *Proc. I.R.E.* **38,** 626 (1950)
21. G. Isborn, *Electronics* **25,** No. 4, 121 (1952)

Optimizing Multiplication Factors of Heterogeneous Reactors

A simplified method is presented for calculating multiplication factors of heterogeneous reactors to which diffusion theory is applicable. The technique eliminates the need for elaborate computing equipment when surveying the characteristics and limitations of various reactor types. Examples are given

By IVAN C. ATKINSON*
and RAYMOND L. MURRAY
North Carolina State College
Raleigh, North Carolina

REACTOR PERFORMANCE can be improved greatly by optimizing various design features so as to achieve a suitable balance in operating characteristics. The methods described in this article simplify calculation of the effect of various material and configuration changes on a reactor's multiplication factor.

The multiplication factor k_∞ plays a key role in reactor design analysis. Defined as the number of neutrons made available per neutron starting the cycle in an "infinite" accumulation of moderator and fissionable material, k_∞ must be considerably larger than unity to permit a finite reactor to be of reasonably small size.

Heterogeneous reactors of the Hanford, Oak Ridge, and Brookhaven type, as well as those in operation in England, are fueled with natural uranium (0.71% U^{235}), and use graphite as the moderator (*1*). Their design was based on theoretical and semi-empirical graphs of the factors of which k_∞ is composed. Examples have been presented for the special combination of natural uranium and graphite (*2*).

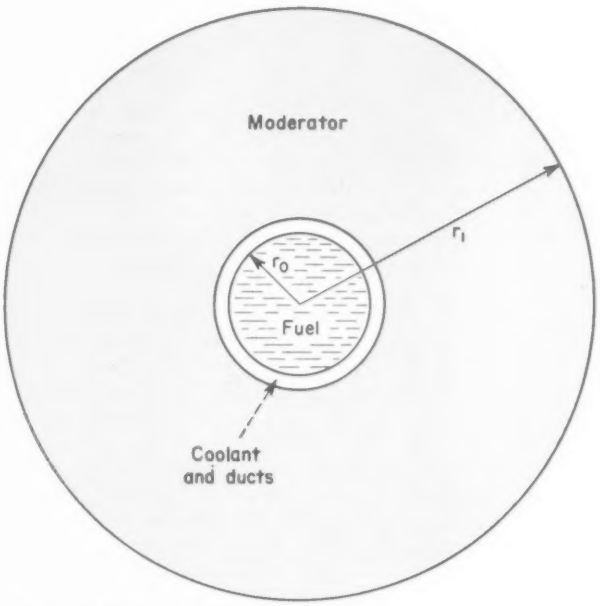


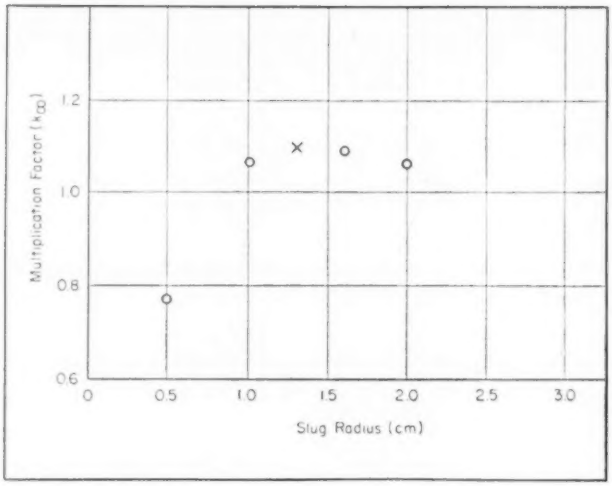
FIG. 1. Cell of heterogeneous reactor

The growing interest in nuclear power means that investigations will be made of many other types of reactors (*3*). In such analyses, there is a freedom of choice of moderators—graphite, light water, heavy water and beryllium, and of fuels—natural uranium, isotopically enriched uranium, and perhaps U^{233} or plutonium.

Calculations

The tedious computation of the multiplication factor is one of the problems facing designers in evaluating

* Based on work performed by this author as part of the requirements for the degree Master of Science in Nuclear Engineering.



Results of Reactor Formulas

Factors	*Approximate*	*Exact*
Thermal		
F	1.120	1.1155
$E - 1$	0.0359	0.0367
f	0.899	0.8986
Resonance		
F	1.042	1.0416
$E - 1$	1.036	1.014
p	0.895	0.8945
k_{∞}	1.094	1.093

FIG. 2 (left). Test of general optimization formula. Cross denotes point computed using optimization formula; circled points computed individually

the relative merits of different combinations and physical arrangements of material. The mathematical basis for calculating k_{∞} has been described previously (*4*, *5*). It is postulated that elementary diffusion theory is applicable to thermal neutrons in a two-region element of the reactor, composed of central fuel cylinder, surrounded by the appropriate amount of moderating material. Formulas involving the modified Bessel functions have been derived for f, the thermal utilization factor (the fraction of thermal neutrons absorbed in uranium) and the resonance escape probability p, (the fraction of neutrons escaping resonance capture).

For a given type of reactor, the largest value of k_{∞} is determined by trial-and-error variation of the reactor's materials and dimensions. By judicious choice, the amount of labor can be reduced, but the thorough exploration of a wide variety of uranium enrichments, types of metal ducts, coolants, and moderators may be prohibitive because of the lack of manpower, time, or a high-speed computer. With this difficulty in mind, the authors sought a relatively simple and quick method for finding the optimum k_{∞} for heterogeneous reactors of the type to which elementary diffusion theory is applicable. The goal was to devise a procedure that eliminates the need of special tables and employs only a hand calculator. Further, it was desirable for the method to admit scrutiny of the effects that yield high or low values of the multiplication factor, and to predict limits of various poisons that might be allowed. The techniques described here and applied to sample cases are believed to be useful in restricting the range of interest, after which more detailed and accurate calculations can be made.

Analysis

The infinite multiplication factor is expressed as $k_{\infty} = \epsilon\ p\ f\ \eta$, where ϵ is the fast fission factor and η is the number of fission neutrons per neutron absorbed in uranium. It may be shown that the variation of ϵ with small changes in fuel dimensions is slight (*6*). Further, η is a constant for a particular fuel. The functions p and f are dependent on physical constants and the dimensions of the fuel and moderator.

The magnitude of k_{∞} for a reactor is assumed equal to the value for one typical portion of the system, the "cell." The cell, in the conventional arrangement of materials, consists of a line of cylindrical fuel slugs of indefinite length, embedded in a block of moderator. For purposes of calculation it is convenient to use a substitute cell, with the same cross-sectional area, but cylindrical in shape. Figure 1 shows an idealized arrangement of the cell in which all poisoning materials are grouped in a single layer adjacent to the slugs. In a typical design, slugs are canned within metal to prevent escape of fission products. Annuli for coolant are provided, and the metal casings of the annuli serve to isolate the coolant from the moderator.

The radii r_0 and r_1 refer to the outer boundaries of the slug and moderator, respectively. The process of optimization of k_{∞} consists of making a choice of r_1 for a particular set of materials, and finding the value of r_0 that yields the largest k_{∞}. The largest of the maxima for various cell radii constitutes the final best value of k_{∞}. The mathematical counterpart of this procedure is to find r_0 for fixed r_1 that satisfies the relation $d(pf)/dr_0 = 0$, assuming that ϵ and η are constant. The factor p may be expressed in the form $\exp -[(1/f_r) - 1]^{-1}$, where f_r is analogous to f, but refers to neutrons in the resonance region rather than to thermal neutrons. The condition on maximum k_{∞} becomes

$$\frac{d(1/f)}{1/f} = \frac{d(1/f_r)}{(1/f_r - 1)^2} \qquad (1)$$

The reciprocals of the thermal and resonance utilization factors for a simple two-region system can be calculated by use of Eq. 2, remembering that the factors change when the resonance region is being investigated,

$$\frac{1}{f} = 1 + \frac{V_1\Sigma_1}{V_0\Sigma_0} F + (E - 1) \qquad (2)$$

where

$$F = \frac{\varkappa_0 r_0}{2} \frac{I_0(\varkappa_0 r_0)}{I_1(\varkappa_0 r_0)} \tag{3}$$

$$E = \frac{V_1}{V_0} \frac{\varkappa_1 r_0}{2} \left[\frac{I_1(\varkappa_1 r_1)K_0(\varkappa_1 r_0) + I_0(\varkappa_1 r_0)K_1(\varkappa_1 r_1)}{I_1(\varkappa_1 r_1)K_1(\varkappa_1 r_0) - I_1(\varkappa_1 r_0)K_1(\varkappa_1 r_1)} \right] \tag{4}$$

The functions I_0, I_1, K_0, and K_1 are modified Bessel functions of the first and second kind, zero and first order (*7, 8*). For all other symbols the subscript "0" refers to fuel and "1" to moderator. Volumes (or cross-sectional areas) are referred to by V, macroscopic cross-sections by Σ, and inverse diffusion lengths by $\varkappa$.

To avoid the higher-order Bessel functions resulting from differentiation, an approximate but simpler function of r_0 and r_1 was developed. The series expansions of the several Bessel functions was inserted in Eqs. 3 and 4. Approximate expressions thus obtained are

$$F \simeq 1 + \frac{(\varkappa_0 r_0)^2}{8} \tag{5}$$

$$E - 1 \simeq \frac{(\varkappa_1 r_1)^2}{2} \left[\log_e \left(\frac{r_1}{r_0} \right) - \frac{3}{4} \right] \tag{6}$$

The tabulated comparison of the exact and approximate formulas for a two-component system, natural uranium $r_0 = 1.4$ cm, graphite $r_1 = 11.5$ cm, indicates the accuracy of the formulas.

The presence of poisons at the surface is included by replacing the product $V_1\Sigma_1$ in the thermal utilization formula by $V_1\Sigma_1 + V_p\Sigma_p$, where $V_p\Sigma_p$ is the *total* poison cross-section. An extension of the heterogeneous theory to three regions—fuel, moderator and poison annulus—was used to test this approximation. The thermal utilization for a D_2O moderated natural uranium reactor with a $\frac{1}{16}$ in.-thick iron annulus, slug radius 1.6 cm, cell radius 15 cm, is calculated to be 0.846 by the approximation method and 0.838 by the three-region method. The slight discrepancy is due to the underestimate of the flux depression due to the iron layer.

Substitution of the formulas for F and E in $1/f$ and $1/f_r$ and forming the derivatives with respect to r_0 in Eq. 1 yields a general working formula

$$\frac{V_1}{V_0} = \sqrt{\frac{\Sigma_0}{\Sigma_1} \frac{\Sigma_0'}{\Sigma_1'}} (1 + \alpha) A \tag{7}$$

where

$$A = \frac{(1 + a_1 + a_2)(1 + b_1 + b_2)}{(1 + c_1 + c_2)(1 + d_1 + d_2)^2}$$

$$a_1 = \frac{E - 1}{1 + \alpha}, \; a_2 = \frac{V_p\Sigma_p F}{V_0\Sigma_0}$$

$$b_1 = -\frac{1}{2(1 + r_0/B)}, \; b_2 = \frac{(\varkappa_1' r_1)^2}{4\alpha'}$$

$$c_1 = \frac{(\varkappa_1 r_1)^2}{4\alpha}, \; c_2 = \frac{V_p\Sigma_p}{2\alpha V_0\Sigma_0}$$

$$d_1 = F' - 1, \; d_2 = \frac{E' - 1}{\alpha'}$$

$$\alpha = \frac{V_1\Sigma_1}{V_0\Sigma_0}, \; B = \frac{2(2.67)}{\rho}$$

Primed symbols refer to the resonance constants.

The calculation procedure consists of evaluating all material constants, choosing a cell radius and the thicknesses of ducts and cooling annuli, inserting a reasonable trial slug radius and solving for V_1/V_0. This gives a new radius r_0. Iteration yields the best value. A typical test of the general optimization formulas is given in Fig. 2 for a graphite-natural-uranium reactor of cell size 11.5 cm. The slug radius at which the highest k_∞ occurs agrees well with that obtained from the curve computed pointwise.

To accelerate the convergence of the iteration, advantage may be taken of two simpler approximate forms of the relation.

Case A. Moderator absorption much greater than duct and coolant poison. An example is the ORNL machine, with an aluminum coolant duct

$$\frac{V_1}{V_0} \sim \left(\frac{\Sigma_0\Sigma_0'}{\Sigma_1\Sigma_1'} \right)^{1/2} \tag{8}$$

The variation with r_0 in $\Sigma_0' = N_u 1.652 \times 10^{-24}(1 + B/r_0)$ may be omitted in this approximation.

Case B. Duct and coolant poison much greater than moderator absorption. An example is a heavy water reactor with stainless steel slug coatings and ducts

$$\frac{V_1}{V_0} \sim 2\left(\frac{V_0\Sigma_0}{V_p\Sigma_p} + 1 \right) \frac{\Sigma_0'}{\Sigma_1'} \tag{9}$$

Applications

The convenience and versatility of the method can be illustrated by applying it to several problems. Cross sections used are from Ref. *9*.

ORNL graphite reactor. This reactor uses natural uranium fuel.

The aluminum coolant duct is diamond-shaped with $1\frac{3}{4}$-in. sides. The slug center line spacing is 8 in., and the slugs are 1.1 in. in diameter. Since aluminum is a weak absorber $\Sigma_p = 0.0133$ cm^{-1}, Eq. 8 may be used for first estimates taking $\Sigma_0 = 0.351$ cm^{-1}, $\Sigma_1 = 3.6 \times 10^{-4}$ cm, $\Sigma_0' \simeq 0.0781$ cm^{-1}, $\Sigma_1' = 0.0108$ cm^{-1}. With the cylindrical cell radius $r_1 = 11.48$ cm, $V_1/V_0 = 84$ and the first estimate of slug radius is 1.24 cm. This value is substituted in the right side of Eq. 7 and V_1/V_0 is computed again. The constants are

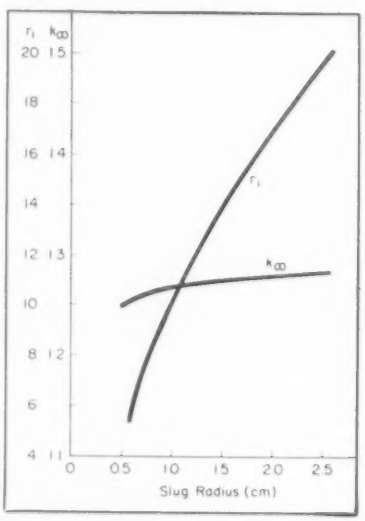


FIG. 3. Cell radius (r_1) and optimum multiplication factor (k_∞) for heavy water, natural uranium reactor

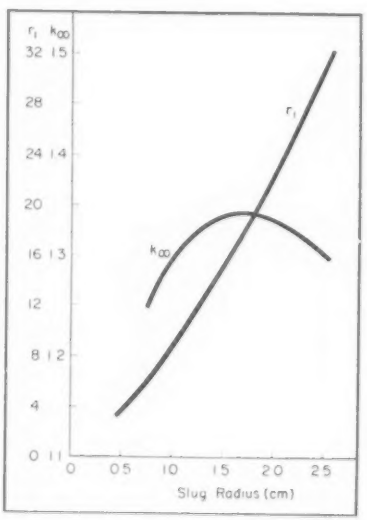


FIG. 4. Cell dimensions for optimum multiplication factor; 1% U^{235}, D_2O reactor with $\frac{1}{32}$-in. stainless steel tube

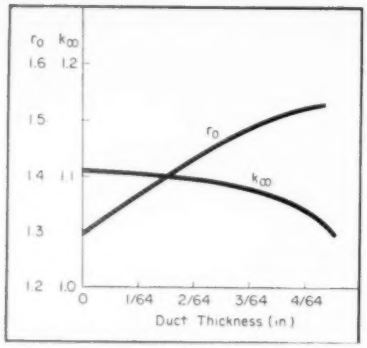


FIG. 5. Effect of iron duct thickness on optimum slug radius (r_0) and multiplication factor (k_∞). Natural U, graphite reactor

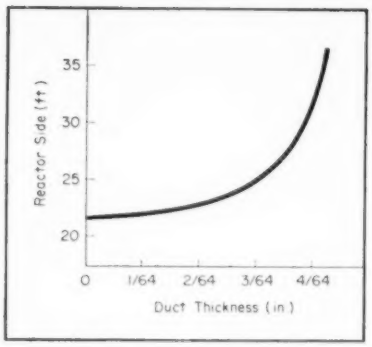


FIG. 6. Variation of critical reactor size with iron duct thickness. Natural uranium, graphite reactor

$$a_1 = 0.036,\ a_2 = 0.012$$
$$b_1 = -0.094,\ b_2 = 0.040$$
$$c_1 = 0.153,\ c_2 = 0.064$$
$$d_1 = 0.033,\ d_2 = 0.119$$
$$\alpha = 0.086,\ \Sigma_0' = 0.096$$

This gives a new ratio $V_1/V_0 = 76.0$, for which $r_0 = 1.31$ cm, slug diameter 1.03 in. If it is presumed that the ORNL reactor was designed to give optimum k_∞, the agreement with the actual dimension 1.1 in. is quite adequate for purposes of estimation.

Lattice arrangement. To find the lattice configuration giving the largest multiplication factor, a compromise normally must be made between reactor size, as determined by multiplication factor k_∞, and the total heat transfer surface, as fixed by slug dimensions. The lattice parameters r_0 and r_1 that yield the largest value of k_∞ for the moderator and fuel used regardless of power considerations may be found by a sequence of applications of Eq. 7. Figure 3 shows a graph of compatible r_0 and r_1 and the values of k_∞ for a D_2O-natural-uranium reactor. The largest value of the product ρf occurs at $r_1 = 8$ cm, $r_0 = 0.77$ cm. Because of the fast fission factor, the multiplication factor keeps rising as the slug size is increased, within the range of slug radii considered.

Effect of canning. As an example, an enriched uranium, liquid-metal cooled heavy water reactor will be considered. To withstand corrosion of the fuel element by the liquid metal coolant, it is necessary to coat the slug with a metal such as iron or stainless steel (*11*). We wish to find the slug radius yielding the optimum k_∞ with a variety of lattice arrangements, assuming an arbitrary metal thickness t of $\frac{1}{32}$ in. of stainless steel. The U^{235} content of the uranium will be taken to be 1%, for which $\Sigma_0 = 0.439$, and $\kappa_0 = 0.80$.* Using $\Sigma_p = 0.255$, $V_p/V_0 \simeq 2t/r_0$, and $\Sigma_1' = 0.0313$, Eq. 9 may be used to obtain a graph of compatible slug and cell radii. Values of k_∞ for each set may be computed from Eqs. 2, 5, and 6. Figure 4 shows the results of these two operations. From such graphs may be found a practical combination from the standpoints of heavy water cost and heat transfer surface. If desired, more careful calculations may be made in more restricted regions of practical interest.

Duct thickness vs. slug size. The method also is useful in determining the effect of thickness of coolant ducts on the optimum slug size, with fixed slug spacing. Both the structural strength and corrosion resistance of coolant ducts are improved with increases in thickness. Estimates of the maximum metal thickness that can be tolerated from the nuclear standpoint, so as to maintain a value of k_∞ larger than unity, are readily made by the use of Eqs. 7 and 8. Figure 5 shows the trends in optimum slug radius and k_∞ with thickness of iron ($\Sigma_p = 0.206$ cm^{-1}) duct in a natural uranium graphite reactor of the ORNL fuel element spacing. The trend in cubical reactor dimensions (side S) with poisoning is shown in Figure 6. The critical condition used was $k_{eff} = k_\infty/(1 + B^2M^2)$ where $B^2 = 3(\pi/S)^2$, and k_{eff} is taken to be 1.04 (*5*). As expected, the slug size must be increased to compensate for duct absorption. The net result is a reduction in multiplication factor and an increase in reactor size.

* The trancendental formula of transport theory $\kappa/\Sigma = \tanh \kappa/\Sigma_s$ is solved for κ, using $\Sigma_s = 0.3879$ and $\Sigma = 0.8266$.

BIBLIOGRAPHY

1. H. S. Isbin, NUCLEONICS **10,** No. 3, 10 (1952); NUCLEONICS **10,** No. 6, 65 (1952)
2. E. A. Guggenheim, M. H. L. Pryce, NUCLEONICS **11,** No. 2, 50 (1953)
3. NUCLEONICS **11,** No. 6, 49 (1953); "Reports to the U. S. AEC on Nuclear Power Reactor Technology" (U. S. AEC, Washington, D. C., 1953)
4. A. M. Weinberg in "The Science and Engineering of Nuclear Power," p. 70, Clark Goodman, ed. (Addison Wesley Press, Cambridge, Mass., 1949)
5. S. Glasstone, M. C. Edlund, "The Elements of Nuclear Reactor Theory" (D. Van Nostrand Co., Inc., New York, 1952)
6. R. L. Murray, A. C. Menius, Jr., NUCLEONICS **11,** No. 4, 21 (1953)
7. "Tables of the Bessel Function $Y_0(x)$, $Y_1(x)$, $K_0(x)$, $K_1(x)$, $0 \leq x \leq 1$," (National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., 1948)
8. "Bessel Functions," Vol. VI, British Association Mathematical Tables (Cambridge University Press, 1937)
9. Neutron Cross Sections, AECU-2040 (Office of Technical Services, Department of Commerce, Washington, D. C., 1952)
10. NUCLEONICS **10,** No. 2, 24 (1952)
11. R. N. Lyon, ed., "Liquid Metals Handbook, 2nd ed." (U. S. Government Printing Office, Washington, D. C., 1952)

Reactors Are Inherently Simple

APART FROM the rather hard to assess costs which safety and possible lack of long-term reliability may add to reactor systems, I think there is an excellent chance that nuclear power reactors will ultimately turn out to be simpler, and cheaper, than conventional steam boilers. A modern steam boiler is an extraordinarily complicated gadget—this complication results from the fuel injection and air injection systems; from the waste handling systems; and from the extremely high temperature. A nuclear chain reaction produces its own oxygen—that is the neutrons—in just the right amount to keep the fire burning properly. If it has a negative temperature coefficient it will be inherently self-regulating; and because of its first-order temperature independence, no temperature in the system need exceed the temperature of the working fluid by more than is needed to transfer the heat from the point of generation to the turbine.

In a conventional steam plant which costs about $160 per kw, the generating and electrical equipment costs about $90 per kw, the boiler, which the reactor replaces, about $70 per kw. What I am claiming is that the potential inherent simplicity of a nuclear chain reaction may ultimately allow such systems to be built for less than $70 per kw.

—From talk by Alvin M. Weinberg, before University of Illinois Sigma Xi chapter, Feb. 22, 1954.

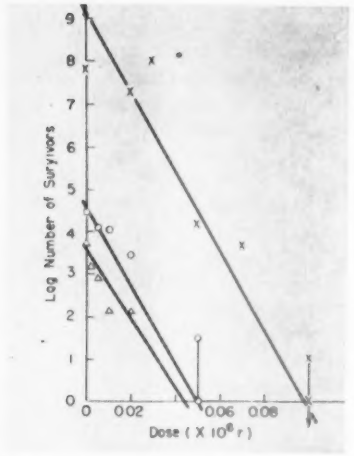


FIG. 1. Survival curves for *Staphylococcus aureus* at dose rate of 140,000 rep/sec. Cells grown aerobically on nutrient broth

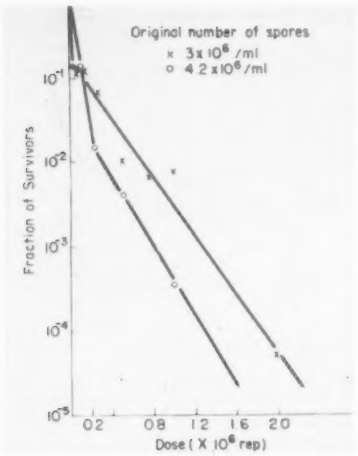


FIG. 2. Survival curves for *Bacillus larvae* spores at dose rate of 140,000 rep/sec. Irradiated in honey at room temperature

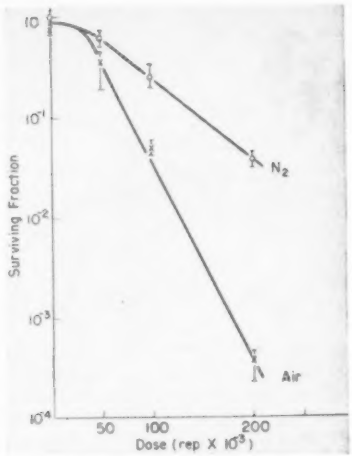


FIG. 3. Survival curves in air and nitrogen for *S. faecalis 10Cl.* Cells grown and irradiated as told in text for *E. coli B/r*

RADIATION STERILIZATION VII

Problems in Using High-Voltage Electrons for Sterilization

Using experimental studies of bacteria and enzyme inactivation, dose-rate dependence, and side effects as a base, the authors point out the areas where research is needed before commercial sterilization is possible

By W. D. BELLAMY
and E. J. LAWTON
General Electric Research Laboratory
Schenectady, New York

IN ANY STERILIZATION of foods or drugs, the effect of the process on the sterilized material is as important as killing the contaminating microorganisms. If irradiation sterilization is to be used commercially, the products of irradiation must be nontoxic and acceptable in odor, flavor and appearance.

There is ample evidence in the literature indicating that proper doses of ionizing radiation will sterilize, but much less information on the chemistry of irradiated foods and drugs. This type of information is essential for adequate appraisal of irradiation sterilization.

This article deals with our own limited experiments related to radiation sterilization; it also points out some of the areas for further research. Our experiments have included studies of inactivation of bacteria and enzymes, and radiation-induced side effects.

Experimental Apparatus

The factors that limited the earlier research of W. D. Coolidge (*1, 2*) and others—namely, limited penetration and low intensity of electron beams—have been overcome by present-day apparatus. The source used in the experiments reported here is a modified 1-Mev peak resonant-transformer X-ray unit. The heavy metal target

has been replaced by a thin stainless-steel window. The tube has been thoroughly evacuated and operates as a sealed-off self-contained unit.

The present experimental machine operates at 800 kv peak and 200 μa beam current. At 10 cm from the window it delivers a dose of about 286,000 rep/sec. The beam is completely stopped by 3.3 mm of water. A 2-gm sample spread over a 2-in. circle (approximately 0.1 gm/cm^2 absorber) when placed at this distance will receive a dose that does not vary by more than 15% from center to edge and from top to bottom.

Sensitivity of Bacteria

A survey of some of the factors affecting the sensitivity of bacteria to this type radiation has been made. *Staphylococcus aureus 209* or *Micrococcus pyogenes* var *aureus* was chosen for some of these studies because it is a common contaminant. Several different concentrations were irradiated in phosphate buffer and in broth. Figure 1 is a plot of the logarithm of the number of survivors against the dose. The cells, in three different original concentrations, were irradiated in M/15 phosphate buffer *p*H 7.0 at room temperature. It is apparent that a straight line best fits these result.

As Lea (*3*) and others have pointed out, the most convenient method for expressing such results is as the "mean lethal dose," i.e., the dose necessary to reduce the number of survivors to 37% of the original. The curve is described by the equation

$$N = N_0 e^{-D/D_0}$$

where N = number of survivors of dose D, N_0 = original number, and D_0 = dose at which there is an average of one effective hit per organism.

Irradiation of dry or frozen *S. aureus* produces similar survival curves. However, the mean lethal dose increased from 5,000–6,000 rep for cell suspensions to about 25,000 rep for cells irradiated at −78° C. The mean lethal dose for dry *S. aureus 209* irradiated at room temperature is slightly higher than for frozen cells at −78° C.

Spores of *Bacillus subtilis* were found to be more resistant to radiation than vegetative cells but were only slightly more resistant than dry or frozen staphylococci. The mean lethal dose was found to be about 35,000 rep. Contrary to the finding with staphylococci, the spores were found to be only slightly affected by water or freezing. The mean lethal dose was of the order of 37,000 to 44,000 rep for dry or frozen spores.

Bacillus larvae, the cause of foul brood in bee hives, forms one of the most heat resistant bacterial spores known (*4*). Figure 2 indicates that it is also quite resistant to ionizing radiation. From these preliminary tests it appears to have a mean lethal dose of the order of 300,000 rep. It is also apparent that the spores consist of at least two species of radiation resistance; about 10% of the spores are many times as resistant as the majority.

Dose-Rate Dependence

It has been reported that the survival of bacteria is not dose-rate dependent (*3*). This fact has been confirmed with *Escherichia coli B/r* over a dose range of 8,000-fold. We have found similar survival curves for *E. coli B/r* when exposed to X-rays at a dose rate of 1,000 rep/min and to high-voltage electrons at a dose rate of 140,000 rep/sec. These results are similar to those reported by Hollaender, *et al.* (*5*) for X-ray dose accumulated at 1,000 rep/min. The cells for these experiments were grown anaerobically in broth (1% yeast extract, 1% hydrolyzed casein, 0.5% phosphate, 0.1% glucose *p*H 7.0) at 34° C for 20 hr. The cells were centrifuged and resuspended in M/15 phosphate buffer, *p*H 7.0. The cells were irradiated at 2–5° C in stainless-steel dishes and plated in the usual manner. The mean lethal dose for *E. coli* of 5,000–7,500 rep is similar to that reported for doses accumulated at rates of the order of 10^6 rep per 10^{-6} sec (*6*).

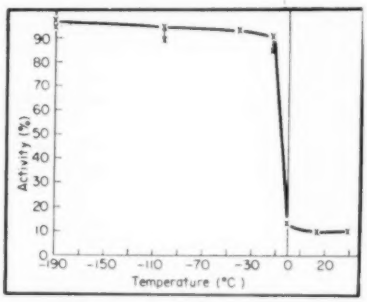


FIG. 4. Effect of temperature on inactivation of pepsin solution by 2.5 × 10^6 rep. Pepsin irradiated at 10 mg/ml in water and assayed for activity at 0.5 mg/ml. Samples irradiated in air in stainless-steel dishes; temperatures determined with recording thermocouple

TABLE 1—Pepsin Concentration, Dose and Ionic Yield for Solutions and Suspensions Irradiated Neutral at Room Temperature, and Assayed in 0.06 N HCl

Concentration (mg/ml)	$D_0 \times 10^6$ (37% D)	*Ionic yield*
0.1	0.042	0.0142
0.5	0.17	0.0178
1.0	0.34	0.0178
2.5	0.85	0.0178
5.0	1.3	0.0234
10.0	2.6	0.0234
20.0	3.4	0.0356
40.0	6.4	0.0379
Dry	30.	0.22

The increased resistance in the absence of dissolved oxygen reported by Hollaender, *et al.* (*5*) has been found at both high and low dose rates. This oxygen effect has been found for streptococci although to a lesser degree when *Streptococcus faecalis 10Cl* and *Streptococcus lactis L21S* are grown and irradiated under similar conditions. Figure 3 shows the survival curve for *S. faecalis*.

It is thought that the deviation from a first-order survival is due to the chain formations of these streptococci. Direct microscopic examination of the cells after suspension in phosphate buffer by the straining techniques of Knaysi and Ford (*7*) indicate that the average number of living cells per clump is two. It is interesting to note that *S. faecalis*, an organism that frequently survives pasteurization temperatures, is much more resistant to radiation than *E. coli*.

Enzyme Inactivation

Knowledge concerning the inactivation of enzymes by ionizing radiation is essential for application of high-voltage electrons to sterilization.

A few experiments with crystalline pepsin indicate that our results are similar to those found for enzyme inactivation by X-rays at much lower dose rates (*3, 8*). Pepsin solutions were found to exhibit first-order survival curves. Table 1 presents the effect of concentration on the mean inactivation dose. It is apparent that the inactivation dose increases with concentration while the ionic yield (cal-

Radiation Sterilization Series: Prior Articles

1. **Fission-Product Potential of Commercial Reactors and Their Processes,** by Dick Duffey, Oct. '53, p. 8
2. **Van de Graaff Accelerators for Sterilization Use,** by F. L. Foster, D. R. Dewey II, and A. J. Gale, Oct. '53, p. 14
3. **The Resonant Transformer: A Source of High-Energy Electrons,** by J. A. Knowlton, G. R. Mahn, and J. W. Ranftl, Oct. '53, p. 64
4. **Application of Isotopic Sources to Food and Drug Sterilization,** by L. E. Crean, P. J. Isaacs, G. J. Weiss, and F. Fahnoe, Dec. '53, p. 32
5. **Evaluating the Safety of Radiation-Sterilized Foods,** by A. J. Lehman and E. P. Laug, Jan. '54, p. 52
6. **Relative Merits of Cathode Rays and Gamma Radiations,** by S. A. Goldblith and B. E. Proctor, Feb. '54, p. 32

culated as 32 electron volts per ion pair) remains fairly constant over a wide concentration range. The values greater than 5 mg/ml are for suspensions of enzyme rather than solution. These results compare favorably with those of Dale (*8*) on the X-ray inactivation of carboxypeptidase.

Any substance or condition that affects efficiency of transfer of energy from the activated solvent molecules to the solute will decrease the ionic yield. One method of doing this is to immobilize the solvent ions by freezing. The effect of freezing out the solvent in a solution of pepsin is seen in Fig. 4. It is apparent that at this dilution approximately 90% of the inactivation is indirect. No significance should be attached to the slight slope of the curve from −190° C to −10° C.

It has frequently been demonstrated that in a mixed solution some of the energy absorbed by ionization of the solvent will be distributed among the solutes. Thus ethyl alcohol, glucose, thiourea, cysteine, etc., act as protectors for irradiated enzyme solutions. The distribution of the energy depends upon such factors as relative concentration of the solutes, mobility of solvent ions and the relative affinity of the solutes for the radicals of the solvent. Dale (*8*) has reported that thiourea is some 20 times as effective as glucose in the protection of carboxypeptidase against X-rays.

A few examples can be given of the inactivation of enzymes in natural products. Each individual enzyme represents only a small fraction of the total solutes and therefore one would expect considerable protection from indirect action. It has been found that the inactivation dose for a catalase solution of 1 mg/ml is about 25,000 rep while the inactivation dose for the catalase in crushed potatoes is around 5×10^5 rep. While other factors such as peroxidases, etc., are involved in the crushed potato, it shows the order of magnitude of the protection offered by the cell constituents.

Another example of inactivation of an enzyme in natural products is the inhibition of tyrosinase in crushed apples. Tyrosinase is the enzyme that causes cut fruit such as apples to turn brown when exposed to air. In apples the inactivation dose for tyrosinase is 5.7×10^5 rep. If the apple is irradiated at −78° C, the inactivation dose is around 10×10^5 rep. These results again indicate the great degrees of protection offered by the natural cell.

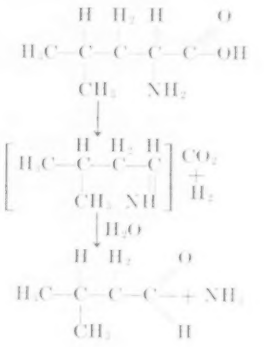
Side Effects

We have found as have others (*9*) that some natural products develop strong objectionable radiation odors while others have slight or very slight irradiation odors. Examples of products with very slight irradiation odors are fresh green beans, fresh liver and bread. Products with strong and undesirable irradiation odors are fresh beef, cooked beef and milk.

It was found that individual proteins showed great differences in the irradiation odor. Several dry proteins were irradiated in air with 5×10^6 rep and then were examined for odor changes, both dry and in water suspensions. The results are presented in Table 2.

All odors were found much stronger in solution than dry. Histone and edestine had very little odor either way. An attempt to correlate the odor of these proteins with their amino acid content was not successful. Therefore, individual amino acids were irradiated in an attempt to locate the sources of the odors. The sulfur-containing amino acids (cysteine, cystine, methionine) and leucine were found to be the worst offenders at a given dose level. No attempt has been made to study the products of cysteine, cystine and methionine.

Isovaleraldehyde has been isolated as the 2,4-dinitrophenylhydrazone from irradiated leucine. This product results from the decarboxylation and deamination of leucine. Thus



In the absence of water, carbon dioxide and hydrogen but no ammonia or nitrogen were found upon examination in the mass spectrograph, and little odor was noticeable. This seems to indicate that the corresponding aliphatic imine is produced by irradiation and that it decomposes upon the addition of water to form isovaleraldehyde and ammonia. The ratio of hydrogen to CO_2 found is greater than the one-to-one, which would indicate that other products than those mentioned were formed. It has been found that aldehydes are also produced from nor- and isoleucine but the irradiation odors are not nearly so pronounced.

It is thus apparent that irradiation odors are not simply related to amino acid composition of proteins. The order and position of the amino acids in the protein molecule must be important factors in determining the response of individual proteins to irradiation.

Discussion

Changes in odor, flavor and appearance of irradiated foods constitute the

TABLE 2—Effect of Protein Composition on Irradiation Odor*

Protein	*Cystine + Methionine* (%)	*Leucine* (%)	*Odor after suspension in water*
Histone	1.8	7.4	Very slight
Edestine	3.3	7.4	Very slight
Bovine plasma albumin	7.3	9.6	Strong
Gelatin	0.9	3.6	Strong—diff. from albumin
Hemoglobin	1.5	15.4	Very slight
Casein	3.5	9.8	Moderate
Enzyme hydrolyzed casein	3.5	9.8	Very strong and unpleasant

* Samples irradiated dry, in air with 5×10^6 rep.

chief obstacles to commercial application. There are many variables involved in the irradiation of materials as complex as foods, and it is not surprising that they are incompletely understood. It is apparent that water content, temperature, chemical composition and structure are variables to be examined in detail. Free-radical acceptors may find use as protectors against radiation side effects; masking of the sensitive group may also be effective.

It has been stated that the killing of bacteria is not dose-rate dependent, but, it is known that certain chemical reactions are dose-rate dependent. An example is vinyl polymerization that proceeds by a free-radical mechanism (*10*). In this case, however, termination is also by free radicals. Dose-rate dependence would be expected in reactions where a strong termination reaction can exist in the presence of a propagation reaction, as is the case in vinyl polymerization. It is questionable whether polymerization reactions of this type are found in food.

Mead reported that oxidation of linoleic acid is dose-rate dependent (*11*). It is not known at present if these reactions are of importance in foods, and further investigations are necessary.

There is no reason for assuming that the products of radiation sterilization will be more toxic than those of other means of sterilization. However, it will be necessary to run the usual animal toxicity tests. We have not run any oral toxicity tests on irradiated products, but we found that dried human plasma irradiated with 2×10^6 rep and 5×10^6 rep passed the standard pyrogen test in rabbits.

In collaboration with Dr. I. Gordon of the New York State Health Department, attempts to produce anaphylactic sensitivity in guinea pigs by injection of irradiated g.p. serum were tried. It was found that serum irradiated with doses up to 3×10^6 rep produced no undesirable effects. The guinea pigs were sensitized by a 6-week series of intracutaneous doses and then challenged with 1.0 ml of the same irradiated g.p. serum after 4 weeks and rechallenged with 1.0 ml intervenous 4 weeks later. These tests are probably more severe than oral toxicity tests, but each irradiated product should be tested separately.

Conclusion

While there are many problems to be solved in radiation sterilization, the authors have no information that would preclude their solution. It is apparent that modifications in preparation and packaging methods will be necessary for proper utilization of cathode rays for sterilization. The present methods of sterilization are the result of considerable expenditure of time and effort, and it is wishful thinking to suppose that cathode rays will be immediately applicable to all problems of sterilization.

BIBLIOGRAPHY

1. W. D. Coolidge, *Science* **62,** 441 (1925)
2. W. D. Coolidge, *J. Franklin Inst.* **202,** 693 (1926)
3. D. E. Lea, "Actions of Radiations on Living Cells" (Macmillan Co., New York, 1947)
4. H. Katznelson, C. A. Jamieson, E. J. Lawton, W. D. Bellamy, *Can. J. Tech.* **30,** 95 (1952)
5. A. Hollaender, G. E. Stapleton, F. L. Martin, *Nature* **167,** 103 (1951); A. Hollaender, W. K. Baker, E. H. Anderson, *Cold Spring Harbor Symp. Quant. Biol.* **16,** 315 (1951)
6. W. Huber, *Die Naturwissenschaften* **38,** 21 (1951)
7. G. Knaysi, M. Ford, *J. Dairy Sci.* **21,** 129 (1938)
8. W. M. Dale, *J. Cell. Comp. Physiol.* **39,** Supp. I. 39 (1952)
9. A. Brasch, W. Huber, *Science* **108,** 536 (1948); B. E. Proctor, D. S. Bhatia, *Food Technol.* **4,** 357 (1950); L. E. Brownell, *et al.*, Progress Report 4 U. S. AEC Project M943 (March, 1953)
10. J. V. Schmitz, E. J. Lawton, J. S. Balwit, *Science* **113,** 718, (1951
11. J. F. Mead, *Science* **115** 470 (1952)

OPTICAL SYSTEMS

INDUSTRIAL PERISCOPES

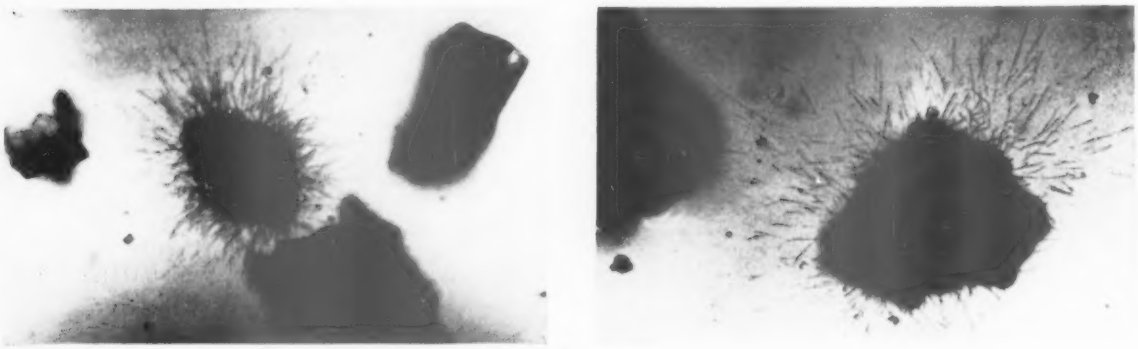
DESIGN
DEVELOPMENT
MANUFACTURE

For nearly half a century Kollmorgen has designed, developed and manufactured precision optics and optical systems for industry and the military.

We have the engineering "know-how", the design personnel and the manufacturing capacity to help you solve your optical problem.

KOLLMORGEN Optical CORPORATION

Plant: 347 King Street • Northampton, Mass.
New York Office
30 Church Street
New York 7, N. Y.



AUTORADIOGRAPHS of active minerals in ore; black (left) and yellow (right)

Using Autoradiography for Quantitative Study of U in Ore

By A. S. BHATNAGAR and P. C. GHOSH
Rare Minerals Laboratory, A.E.C.
New Delhi, India

Neither physical or chemical methods provide a quantitative estimate of the percentage of uranium present in only the radioactive-mineral portion of an ore unless the ore consists of a pure mineral or the mineral is completely separated from the ore. Such information, however, is valuable in assessing the economic possibility of beneficating a low-grade ore.

Tyler and Marias (*1*) have used autoradiography to determine the relative activity of various radioactive grains. This article describes a similar autoradiographic method that makes it possible to calculate the percentage uranium in radioactive minerals without their having to be separated from the ore.

A combination of radioassay and autoradiography provides the required data. Radioassay of the sample gives the percentage of uranium in the ore. Since radioactive particles can be distinguished from nonradioactive ones in an autoradiograph of the sample, a fairly accurate determination of the fraction of radioactive mineral in the ore is obtained by counting a large number of particles. Percentage of uranium in the radioactive mineral is then calculated.

TABLE 1—Analysis of U_3O_8 in Mineral Content of Ore

Concentrate	*Radioassay U_3O_8 in ore (%)*	*Autoradiograph counting*		*U_3O_8 content of radioactive mineral (%)*
		Active particles (black)	*Nonactive particles*	
1	34	688	1,213	93.9
2	88	767	57	94.5

TABLE 2—Analysis of U_3O_8 in Two Minerals in Ore

Concentrate	*Radioassay U_3O_8 in ore (%)*	*Autoradiograph counting*			*U_3O_8 in mineral (%)*	
		Active yellow particles	*Active black particles*	*Nonactive particles*	*Yellow*	*Black*
A	0.215	11	4	4,500	54.6	92.4
B	47.4	8	639	609		

Examples

Two concentrates from different stages in the benefication of an ore were taken. The samples were sized closely and assayed for their activity. They were then exposed separately to Kodak NT1A nuclear track plates (50-micron thickness). The plates were immersed in warm water at about 90° F while dispersing the particles for exposure; this allows embedding of the particles in the softened emulsion so that they are not displaced during processing (*2*).

After exposure for about 240 hours, the plates were developed and the autoradiographs counted for active and nonactive particles with a microscope. The number of particles counted depends on the relative number of active particles and the accuracy desired.

Results of this determination are shown in Table 1. Percentage U_3O_8 in the mineral is given by

$$\frac{\text{Total number of particles}}{\text{Number of active particles}} \times \%\ U_3O_8 \text{ in ore}$$

That the method can also be applied when two minerals are present in an ore is demonstrated by results obtained from two different concentrates of another ore. These concentrates were obtained from early stages in beneficiation. The autoradiographs revealed that there were two distinct radioactive minerals present. One was black, the other yellow; autoradiographs of each are shown in the figure on page 58.

Table 2 shows the results of an analysis of the two concentrates. The value for the black mineral is in good agreement with the values in Table 1.

The percentage of U_3O_8 in the two radioactive minerals, 1 and 2, in the concentrates A and B that assayed $a\%$ and $b\%$ U_3O_8 respectively, was calculated as follows: For concentrate A, N_A = total number of particles counted, and N_1 and N_2 = the number of active particles of types 1 and 2 respectively. For concentrate B, n_B, n_1 and n_2 denote the corresponding quantities. If x and y denote the percentages of U_3O_8 in the minerals 1 and 2 respectively, the total U_3O_8 content in sample A is

$$\frac{N_1}{N_A}x + \frac{N_2}{N_A}y = a$$

and in sample B

$$\frac{n_1}{n_B}x + \frac{n_2}{n_B}y = b$$

Solution of these equations gives the percentage of U_3O_8 in the two minerals.

No account has been taken of any difference in the densities of the active and nonactive particles on the assumption that, as the concentrates were obtained by gravity separation, this difference would be small. In any other case, the densities can be approximated from the densities of the concentrates and of the low-grade ore itself.

* * *

The authors thank D. N. Wadia, Geological Adviser, A.E.C. and V. R. Khedker, Director, Indian Bureau of Mines, for supplying the concentrates used in this study and for giving encouragement.

BIBLIOGRAPHY

1. S. A. Tyler, J. J. Maraus, *J. Sediment. Petrol.* **2**, 145 (1941)
2. H. Yagoda, "Radioactive Measurements with Nuclear Emulsions," p. 176 (John Wiley & Sons, New York, 1949)

A Biosynthesis of C^{14}-Labelled Glycogen

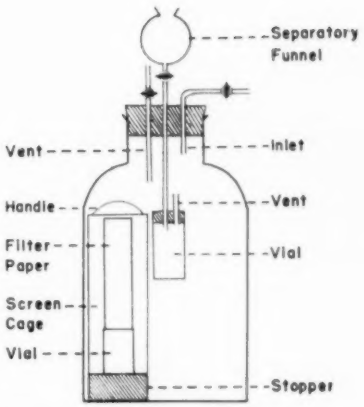
By C. C. HASSETT, W. H. SUMMERSON, and F. SOLOMON
Chemical Corps Medical Laboratories Army Chemical Center, Maryland

Labelled organic compounds of many kinds have been prepared by biosynthetic procedures, among them both carbohydrates and proteins (*1*). Most such experiments have been done with vertebrates. Zamecnik *et al.* (*2*), have shown, however, that labelled fibroin is formed in the giant silkworm, *Platysamia cecropia*, when C^{14}-containing glycine and alanine are injected into the body cavity. Glycogen labelled with C^{14} has now been produced by exposing the vinegar fly, *Drosophila melanogaster*, to an atmosphere containing $C^{14}O_2$, taking advantage of the fact that newly emerged adult flies are low in glycogen. When ample food is available the glycogen content increases rapidly in the first few days (*3*).

Experimental

Unfed adults less than 24 hours old were collected in a clean bottle and anaesthetized with CO_2. Approximately a thousand flies (1.076 gm) were transferred to the screen cage of the apparatus shown in the illustration on this page. The bottom of this cage was formed by a No. 11 rubber stopper in which was embedded a glass vial holding a 12-cm-long roll of filter paper saturated with $M/10$ sucrose. The screen cage was put into a 2-liter wide-mouth jar, and about 50 gm of $Mg(NO_3)_2{\cdot}6H_2O$ were spread on the bottom of the jar to maintain a constant humidity during the experiment.

The CO_2 generator, assembled on a No. 12 stopper, then was put in place, sealing the jar. This generator consisted of a separatory funnel, the stem of which carried a small stopper by which there was attached a shell vial containing 14 mg of $BaC^{14}O_3$. A second hole in the small stopper provided a vent. Two tubes bearing stopcocks also passed through the large stopper; after the apparatus was assembled they



APPARATUS in which *Drosophila* were exposed to $C^{14}O_2$ enriched air

were used to displace part of the air in the jar with O_2, for preliminary tests had shown that the flies would not survive without this additional supply. The stopcocks were closed and $M/5$ lactic acid was dripped onto the $BaC^{14}O_3$ from the separatory funnel. The evolving $C^{14}O_2$ escaped from the shell vial through the vent, and at the end of the reaction enough lactic acid was run into the vial to drive all the gas into the main container. The entire jar assembly was then enclosed in a large covered battery jar in which there was a liberal supply of soda lime to trap any $C^{14}O_2$ that might escape.

After two days the battery jar was opened and the 2-l jar was transferred to a hood, where the gas in the system was replaced by room air, with all the CO_2 and $C^{14}O_2$ being precipitated as carbonate in scrubbers filled with $Ba(OH)_2$ solution. The screen cage was removed, and the flies were anaesthetized with CO_2, then immediately dropped into 5 ml of hot 30% KOH. After digestion on a water bath for 1 hr, the material was passed through a medium-porosity sintered-glass filter to remove the exoskeletons, and 1.2 volumes of 95% ethanol were added to the filtrate. After several hours of refrigeration, the precipitate was separated by centrifugation at 5,000 rpm for 15 min at 0° C. The crude precipitate was then washed with 60% ethanol, extracted with three por-

NEW LABORATORY INSTRUMENT

α β γ

A general purpose laboratory instrument for the accurate measurement of alpha, beta and gamma radiation. An eleven-stage photo-multiplier tube is used and a Sodium Iodide crystal of diameter 1½″ (3.8 cm) and length 1⅛″ (2.86 cm) is provided for gamma measurement.

Alternative holders for alpha and beta assay work can also be supplied.

The heavy adjustable stand enables the probe unit to be used in any position.

by BURNDEPT of ENGLAND

Other Instruments available

Portable Beta Gamma Radiation Monitors
Portable Neutron Monitors
Rate Meters
Pulse Amplifiers

Nucleonics Division

BURNDEPT LIMITED
ERITH · KENT ENGLAND

Radioactivity of Labelled Glycogen and Its Degradation Products*

Expt. No.	*Glycogen* (mg)	*Glycogen* (cpm)	*CO_2* (cpm)	*Ethanol* (cpm)	*Residue* (cpm)	*Unaccounted for* (cpm)
1	1.18†	4,075	1,170 (28.7%)	‡	746 (18.3%)	2,159 (53.2%)
2	0.58†	2,002	696 (34.8%)	‡	151 (7.6%)	1,155 (57.7%)
3	Commercially prepared glucose	30,440	8,769 (28.9%)	17,728 (58.3%)	2,791 (9.2%)	1,132 (3.7%)
4	0.51†	1,750	348 (20.0%)	760 (43.5%)	448 (25.3%)	194 (11.1%)

* Activity given as counts per minute corrected for background and as percentage of activity of original material.
† Calculated values.
‡ The alcohol product of these experiments was lost in the counting process.

tions of 10% trichloroacetic acid, and reprecipitated from the combined extracts with 1.2 volumes of 95% ethanol in the presence of LiBr, which is known to facilitate the process. The product was further purified, by reprecipitation from distilled water with ethanol, and washed with increasing concentrations of ethanol. After a final acetone wash it was dried *in vacuo* over P_2O_5 (*4*). The activity of the product was measured with a gas-flow proportional counter (Model PC-1, Nuclear Instrument and Chemical Co., Chicago), using 90% commercial argon and 10% chemically-pure methane.

To identify the product as glycogen and show that the C^{14} was a structural part of the molecule, the following procedures were carried out: A portion of the product was hydrolyzed with 1*N* H_2SO_4, and solutions of both the original product and the hydrolyzate were assayed for glucose by the Somogyi-Nelson method (*5*).

Finally, the remaining glycogen was converted into glucose, which was fermented with yeast according to the azide inhibition method of Winzler (*6*). The CO_2 that formed was absorbed in alkali; the remaining fermentation mixture was chilled, then transferred to a micro retort and the alcohol was distilled off, chilled, and transferred to a standard glass planchet for counting.

At first (experiments 1 and 2 in the table on this page) difficulty was experienced in retaining the alcohol long enough to count the activity. After several tests starting with labelled glucose, a successful technique was developed (experiment 3). The planchet was kept at a low temperature with dry ice and was covered with a film of rubber hydrochloride to prevent loss of the alcohol by evaporation. A correction for the absorption of the film was applied (experiment 4).

Radioactive glycogen was produced in three experiments. The yields and activities were as follows: 0.5 mg, 4,448 cpm/mg; 18.6 mg, 2,000 cpm/mg; and 13.3 mg, 3,453 cpm/mg. This material was subjected to the Somogyi-Nelson assay both before and after hydrolysis. Only the hydrolyzed samples possessed reducing power.

After hydrolysis and fermentation of small quantities of the glycogen, the products, CO_2 and ethanol, were found to be radioactive. As shown in the table, the ethanol had approximately twice as much C^{14} as the CO_2, which is in accordance with the number of carbon atoms in these molecules.

The results of these experiments show that a radioactive carbohydrate, whose hydrolyzed form reduces Cu solutions and is fermentable by yeast to ethanol and carbon dioxide, was extracted from *Drosophila*. The substance was precipitated from aqueous solutions by ethanol, and in other ways exhibited the properties of glycogen.

Because the object of these experiments was only to produce labelled glycogen, they were not extended to ascertain the mechanism of labelling, or the positions occupied by the C^{14} in the glycogen molecule. The fact that in experiment 4 the ratio of the radioactivity of the CO_2 and ethanol produced is 1:2 suggests that C^{14} was distributed at random in the glycogen.

BIBLIOGRAPHY

1. N. H. Woodruff, E. E. Fowler, NUCLEONICS **7**, No. 2, 26 (1950)
2. P. Zamecnik, R. B. Luftfield, M. L. Stephenson, C. Williams, *Science* **109**, 624 (1949)
3. C. C. Hassett, unpublished data
4. D. Stetten, Jr., G. E. Boxer, *J. Biol. Chem.* **155**, 231 (1944)
5. N. Nelson, *J. Biol. Chem.* **153**, 375 (1944)
6. R. J. Winzler, *Science* **99**, 327 (1944)

Efficient Shielding with Mallory 1000 Metal...

The superior shielding properties of Mallory 1000 Metal are well demonstrated in the radioactive logging of oil wells. This promising commercial application of atomic research identifies the geological structure through which a well hole is being drilled, by measuring the gamma radiation induced in the strata by neutron bombardment.

By shielding the neutron source with a Mallory 1000 cylinder like the one illustrated, the over-all sensitivity of these surveys is considerably improved. This unusual metal permits the neutrons emitted by the source to pass through. At the same time, it stops the hard gamma rays from the source, which would overshadow the secondary radiation, and prevents them from adding to the induced radiation that is being measured.

IDEAL for many shielding applications

Tests run up to 100 MEV energy level show Mallory 1000 to have 40% higher absorption than lead in the most widely used ranges and even at 100 MEV to have 20% greater absorption. Further tests by our technical staff indicate its superiority for the shielding of cyclotron and synchrotron radiation, and for the storage of radioactive isotopes.

Mallory 1000 is a high density, homogeneous alloy of tungsten, nickel and copper, fabricated by Mallory powder metallurgy techniques. It is readily machined to precise tolerances and to high finish, and has good weathering qualities. Further, its average tensile strength of over 100,000 p.s.i. makes it the ideal material where mechanical strength and dimensional stability are required.

Write for Technical Bulletin on the shielding qualities of Mallory 1000.

Expect more... Get more from **MALLORY**

Serving Industry with These Products:

Electromechanical—Resistors • Switches • Television Tuners • Vibrators
Electrochemical—Capacitors • Rectifiers • Mercury Batteries
Metallurgical—Contacts • Special Metals and Ceramics • Welding Materials

P. R. MALLORY & CO. Inc.
MALLORY
P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

For information on titanium developments, contact Mallory-Sharon Titanium Corp., Niles, Ohio

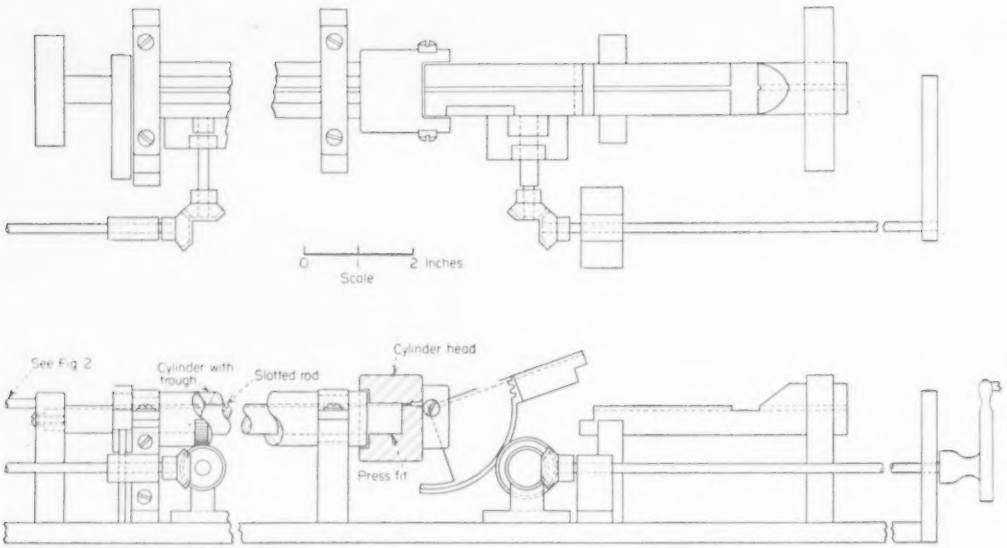


FIG. 1. Details of loading-device construction

Device for Loading Cobalt-60 Cartridges in Tubing for Cancer Therapy

By GEORGE W. CALLENDINE, Jr. and JOSEPH L. MORTON
Department of Radiology, The Ohio State University Medical Center
Columbus 10, Ohio

For irradiation techniques such as interstitial implantations and surface mold applicators, linear sources of irradiating material are desirable in both rigid and flexible forms to meet variations in the structural aspects of tumor location, type, size, etc. Variations in radiation intensity per unit length of the linear sources are often required; these can be produced by spacing small standard radioactive units from zero to several millimeters apart by means of inert spacers. The spacers are needed because the calculated spacing of the active units must remain intact throughout the period of irradiation.

These requirements have been fulfilled by using radioactive cobalt-60 in the form of wire stock cut into short standard lengths, with spacers of inert aluminum wire stock in varying lengths. The standard cobalt-60 "cartridges" have a 0.0508-cm (0.020-in.) diameter and a 0.300-cm (0.118-in.) length. Cartridges and spacers are inserted into either rigid or flexible tubing of 0.030-in. inside by 0.050-in. outside diameter.

Different methods of loading small cylinders into tubing have been studied and a device utilizing a semiautomatic ramrod loading technique developed. The device is shown in Figs. 1 and 2. This "loader" is positioned in an indirect-vision work center. All controls are located outside lead protecting barriers.

The section of the loader into which the Co^{60} cartridges and spacers are positioned before insertion into the tubing consists of a rod and sleeve assembly. In one side of the rod a small slot 0.027-in. wide is carefully milled to a depth of 0.026-in. This rod is fastened rigidly at one end by a mounting bracket. To the other end of the rod is attached a cylinder head.

Concentric with the slotted rod is a cylinder in which is cut a V-shaped trough. This cylinder rides in two bushings and is free to turn on the rod. It is rotated by a worm gear and rack with appropriate bevel gears to facilitate operation of the control mechanism from outside the lead shield.

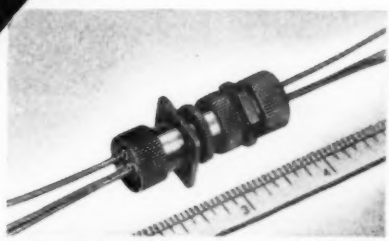
The cylinder trough can be lined up directly over the slot in the rod. When in this "slot-open" position, small cylinders dropped into the trough fall into the slot. Changing the relative positions of the trough and slot, by rotating the cylinder slightly, covers the top of the slot and effectively produces a tube 0.027-in. wide by 0.026-in. deep. Cartridges and spacers in the slot in this "slot-closed" position can be rammed from the slot without changing their relative positions.

A 0.027-in. diameter hole in the cylinder head aligns axially with the covered slot in the rod. Concentric with this hole is a 0.053-in. diameter hole drilled to a depth of 0.5-cm from the open end, thus creating a shoulder against which the tubing to be filled is positioned in a slotted cradle.

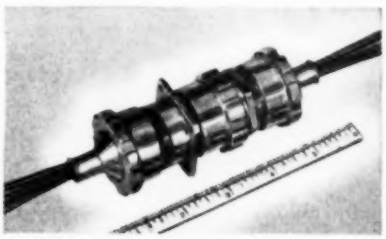
After the desired "load" consisting

Extreme Temperature and Altitude Problems Solved by New Modifiable Titeflex Connector

We have the experience to solve most complex connector problems involving extreme altitudes, temperatures and pressures with space and weight limitations. And within standard design requirements, we can develop special-duty connectors as a part of complete wiring systems.



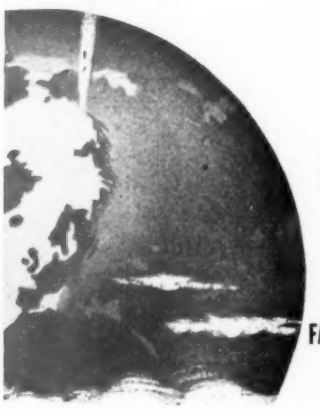
INSTRUMENTATION Connector —07. For moisture and corrosion resistance, temperature ranges of −65°F. to +400°F. Made of Teflon, plug and receptacle mated weigh only ⅔ oz. Length 2". Insulation properties will permit 3500 volts at sea level, 1200 volts at 50,000 feet altitude. Can be made with 2 or 3 pins, current 7 amperes.



MOISTURE-PROOF and resistant to synthetic lubricants. For extreme temperature changes in ranges of −65°F. to +400°F., high altitudes up to 65,000 feet. Resists salt spray, corrosion, vibration. This Titeflex Connector is radio shielded, has positive retention of pins and sockets. 5" in length. Mates with connectors that conform to MIL-C-5015.

CUSTOM WIRING SYSTEMS—For accessory, instrumentation and radio shielded applications. Can be furnished with Titeflex or Standard AN Connectors. Can be sheathed with one or more layers of various metal braids, fiber glass or nylon, and jacketed with silicone or various other compounds. Titeflex will be glad to design, develop and produce complete wiring systems to your specifications.

SPECIAL —07 CONNECTOR. Designed to solve your connector problems in instrumentation with a real saving in space and weight since this connector has no protuberance beyond the flange. Can be designed as an integral part of your wiring or instrument components. Available in 1, 2 or 3 pin arrangements—current 7 amperes, size 1" in length. Receptacle and plug weigh only 11 grams.



All TITEFLEX Connectors can be furnished with thermocouple pins and sockets.

WRITE TODAY for specific information—or send us your specifications. Whatever your requirements, we can usually provide the right answer. Our Engineering Staff will be glad to discuss your problem without obligation.

LET OUR FAMILY OF PRODUCTS HELP YOURS

Titeflex

TITEFLEX, INC.
576 Frelinghuysen Avenue, Newark 5, N. J.

MAIL COUPON TODAY

Please send me your catalog on the Titeflex Connector.

Have your representative call ☐.

NAME_____

TITLE_____

COMPANY_____

ADDRESS_____

CITY_____ ZONE_____ STATE_____

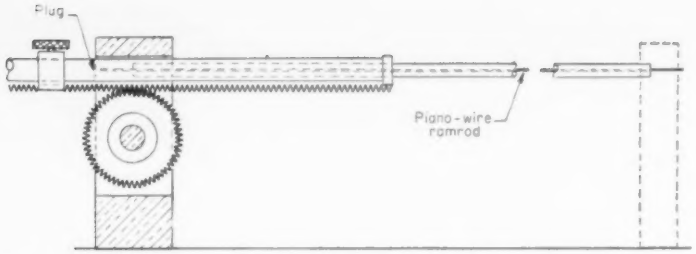


FIG. 2. Ramrod for loading device

of Co^{60} cylinders and inert spacers is positioned in the slot, and the correct tubing is placed against the cylinder-head shoulder, the load is rammed into position in the tubing. The mechanism shown in Fig. 2 facilitates this operation. This ramrod consists of a length of stainless-steel wire of 0.026-in. diameter, with supporting tubing to prevent buckling and gearing to control its motion.

The slotted cradle is provided for holding the tubing while loading (Fig. 3). The bottom of the slot is level with the bottom of the 0.053-in. hole in the open end of the cylinder head. The cradle is in two sections, one fixed and the other pivoting at the cylinder head on two pivoting screws.

The pivoting is used to bend a 0.5-cm long elbow onto the rigid tubing after loading. The end of the tubing away from the cylinder head is closed before loading, so the elbow also functions to seal the "load" into the tubing. The movable section of the cradle is operated from outside a lead protecting barrier by appropriate gearing.

When loading into flexible tubing, the cradle slot is covered by a Lucite plate. To retain the load in the tubing, one end is sealed before loading. After the load is rammed into position through the open end, the tubing is sealed behind the load with a warm soldering iron applied under moderate pressure.

After loading more than 5,000 rigid and/or flexible linear sources over a period of two years, it is possible to study the degree of achievement of the criteria that governed design:

1. Rapidity of loading. Rigid aluminum needles are loaded at the rate of 18 to 24 per hour; nylon "threads" at the rate of 12 to 16 per hour.

2. Simplicity of operation. After 8 to 16 hours practice, a technician can operate the device at the preceding rate.

3. Exposure of operator. When the loader is used in conjunction with an indirect-vision work center and an electromagnetic pickup, the exposure of the operator should never exceed 25 mr/day total body radiation in a 40-hr week of continuous loading. The hands should not receive more than 50 mr/day for the same period. These limits are well within the accepted tolerances of 300 mr/wk total body and 1,000 mr/wk to the hands.

4. Reliability of operation. Jamming has occurred infrequently. When it has occurred, it was possible to clear the trouble completely without resorting to direct vision or incurring overexposure, and without taking more than a few minutes.

* * *

The authors wish to thank Carl McWhirt and Henry Stephan for their technical advice and skill in translating the design into a satisfactory working device. This work was assisted by a contract between the U. S. Atomic Energy Commission and The Ohio State University Research Foundation.

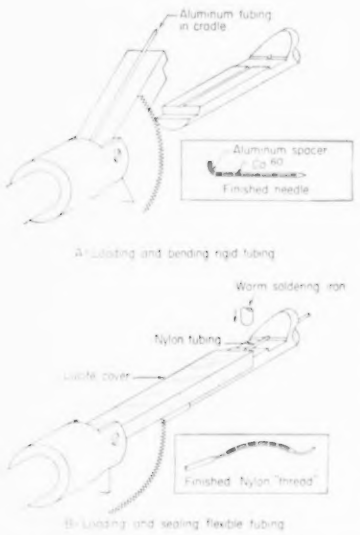


FIG. 3. Use of cradle for sealing rigid and flexible tubing

Activation of Nuclear Isomers by Gamma Rays

By GARMAN HARBOTTLE
Chemistry Department
Brookhaven National Laboratory
Upton, New York

Activation of several nuclear isomers of stable isotopes by X-rays, electrons and heavy charged particles has been reported in the literature (*1*). By means of X-rays from an electron Van de Graaff generator, a group of scientists at Notre Dame have determined nuclear levels in several stable isotopes through observation of nuclear isomerism produced by decay of the excited state (*1*). This article reports the excitation of nuclear isomerism through irradiation of stable isotopes with gamma rays from artificially radioactive sources, notably cobalt-60 and tantalum-182. Possible applications of this phenomenon to shielding and scattering studies are discussed briefly.

Wiedenbeck (*2*) has pointed out that since the absorption of radiation by a nucleus to form an excited state is a line absorption process, higher nuclear levels will not be reached from the ground state through excitation by gamma rays from other nuclei because, in general, the gamma-ray energy will not lie within the very narrow band of energies that can be absorbed. However, with all ordinary laboratory sources of radiation not only primary gamma rays are present, but also Compton gammas resulting from scattering processes in the source or surroundings. The scattered radiation will extend in an energy spectrum from E_γ (the energy of the primary) downwards to the point where photoelectric absorption becomes very probable. If a nuclear isomer of energy E above the

NEW!

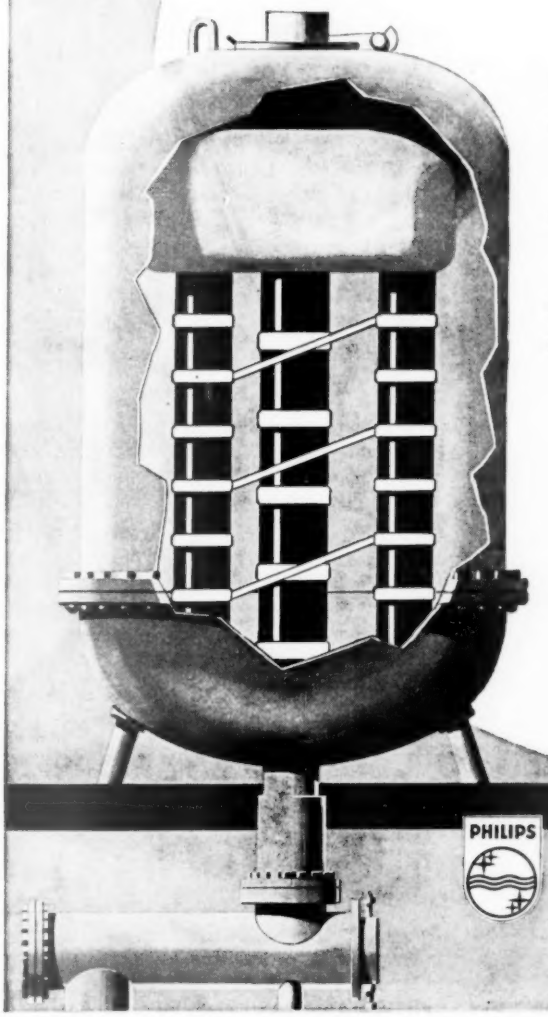
Philips' extensive range of modern Equipment for Nuclear Research and its applications comprises:

- *New compact "open" type H-T Generators with selenium rectifiers and ion accelerating tube. Up to 800,000 V.*
- *Same, in pressurized steel tank, solving space and atmospheric problems. Up to 2,000,000 V.*
- *"Open" type H T Generators. Gas or selenium rectifiers. Ion accelerating tubes of new design. High accessibility. Unequalled high output. Up to 1,400,000 V.*

  Above types can be supplied with exceptionally high stabilisation, low ripple values, various ion sources and targets.
- *Linear Electron Accelerators up to 30,000,000 e V.*
- *Synchro-Cyclotrons, for accelerating deuterons, protons or alpha particles up to 300,000,000 e V. Very high beam currents.*
- *Scalers, ratemeters, dosemeters and radiation monitors for laboratory or defence purposes. Geiger counter tubes.*
- *Radioactive Isotopes (pile & cyclotron produced).*
- *High Voltage Impulse Generators, up to 3,500,000 V. With recording equipment.*

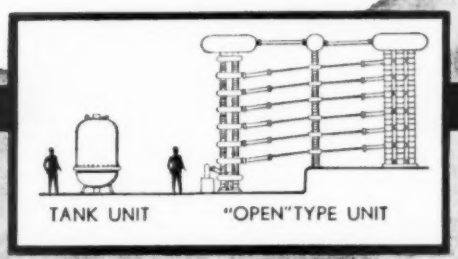
Philips' Nuclear Development Laboratories will gladly inform you on any equipment Philips are prepared to build to your requirements.

High Tension Generators with selenium rectifiers and ion accelerating tube, in pressurized steel tank; PHILIPS' answer to all problems of space and atmospheric conditions.



PHILIPS

Nuclear Equipment



For information please apply to one of the following addresses:

N.V. PHILIPS' GLOEILAMPENFABRIEKEN
Scientific Equipment Department,
EINDHOVEN (Holland)

PHILIPS ELECTRICAL LTD.,
X-Ray Department,
Shaftesbury Avenue, LONDON W.C.2.

NORTH AMERICAN PHILIPS CO. INC.,
Research and Control Instruments Division,
750, South Fulton Ave, MOUNT VERNON N.Y.

Want more information? Use post card insert in this issue.

Activation of Nuclear Isomers by Gamma Radiation*

Source	*Source strength (curies)*	*Detector*	*Saturation (cpm)*	*Gamma flux (r/hr)*	*Ratio (r/hr/cpm)*
1. Co^{60} Thin rods arranged concentrically in lead pig (*6*)	170	In	255 ± 2	768,000	3,000
2. Co^{60} Hollow cylinder, lead pig outside	725	In	100 ± 3	215,000	2,150
3. Co^{60} Same as 2; detector shielded with 1.5 cm Lucite on all sides	725	In	121 ± 2	(215,000)	(1,800)
4. Co^{60} Hollow cylinder in hole in earth; water shielding, no lead	100	In	21 ± 2	44,400	2,100
5. Co^{60} Cylinder in stainless-steel pipe with lead cap. Detector 20 cm (of air) away from source	1,800	In	23 ± 2	(45,000)	(2,000)
6. Co^{60} Same as 5, detector shielded by 1.84 gm/cm² of lead	1,800	In	30 ± 3	(45,000)	(1,500)
7. Ta^{182} Hollow cylinder in water, detector inside source, shielded with 1.5-cm Lucite	1,300	In	124 ± 2	220,000	1,770
8. Co^{60} Same as 5, detector about 2-cm from cylinder	1,800	Cd	15 ± 3	unknown	
		In	205 ± 3	unknown	

* Parentheses indicate approximate values.

ground state can be excited through line absorption of radiation of energy E', followed by emission of a gamma ray of energy $E' - E$, and if $E_\gamma > E'$ then clearly there will be at least a small probability of finding a Compton-scattered gamma of just the right energy E'. There may be levels higher than E' whose decay will also populate the metastable isomeric state. Transitions from the ground state directly to the metastable level through absorption of a photon of energy E are, of course, highly forbidden.

In the case of indium-115, the isotope principally studied in this work, Miller and Waldman (*1*) find that the first level reached by the absorption of X-rays lies at 1.04 ± 0.02 Mev, while another level appears at 1.42 ± 0.02 Mev. This work will be concerned only with absorption to the 1.04 Mev level, since the maximum gamma energy (in cobalt-60) is 1.33 Mev.

Experimental

The procedure consisted simply of exposing a 3-gm pellet of indium in a fixed geometry to the radiation fields of various artificially radioactive sources at the Brookhaven National Laboratory. The pellet was irradiated to saturation, removed and mounted reproducibly relative to a scintillation counter with a NaI(Tl) crystal. Pulses from this counter were amplified and fed through a dual-discriminator anticoincidence pulse-height analyzer whose channel was set to record only the photoelectric peak produced by the gamma ray of the metastable state. Over-all counting efficiency was in the neighborhood of 14%, not taking into account the internal conversion of approximately one-half of the transitions from the metastable state. The activity decayed with the reported half-life of 4.5 hours (*3*).

In a few experiments cadmium was irradiated and the 48-min isomer (Cd^{111}) observed. Except for an appropriate alteration in the energy channel of the pulse-height analyzer, the procedure was the same.

Results

The experimental results are reported in the table on this page. All counting rates are corrected to saturation and for background, and the over-all radiation fluxes are those determined by the method of ferrous sulfate oxidation (*4*). The source geometries are described in the table.

Discussion

The isomer-activation of indium by the absorption of radiation from the Compton spectra of artificially radioactive sources is observed to amount to a saturation activity of roughly 1 cpm in our apparatus for a 3-gm sample of the metal in a flux of 2,000 r/hr. The radiation flux per disintegration per minute (at saturation) is about 140 r/hr.

From these data the order of magnitude of the over-all cross section is 10^{-33} cm², in qualitative agreement with the calculations of Miller and Waldman (*1*). Since five times as

EXTERNAL CONTAMINATION of film badge containers and pocket ionization chambers is checked with device developed by Health and Safety Branch of AEC's Idaho Operations Office. Motor-driven belt conveyor moves equipment to be checked between two G-M tubes that are attached to counting-rate meter. Device shuts itself off if equipment is contaminated. Hand-fed, unit will handle 40 or 50 items per minute

much indium could easily be counted in the same geometry, and about 0.3 cpm above background (about 7 cpm) can be detected with certainty, the limit of detection is about 130 r/hr where the energy spectrum is that of cobalt-60 radiation in a cavity in earth or water.

As a detector for gamma-radiation, the phenomenon of resonance activation has the practical disadvantage of extreme insensitivity but a compensating advantage of very high resolution. For example, Guth (5) calculates that the width of the energy level at 1.04 Mev is only 4 mv. Thus indium constitutes a virtually monochromatic detector for gamma radiation of energy 1.04 Mev. It seems possible that with the advent of radioactive sources in the kilocurie region, isomer activation in a series of stable isotopes that have gamma-ray resonances at different energies, might prove useful in shielding and scattering studies, since in any continuous spectrum the flux of radiation within several specific monochromatic bands could be determined.

* * *

This work was performed under the auspices of the U. S. Atomic Energy Commission.

BIBLIOGRAPHY

1. W. C. Miller, B. Waldman, *Phys. Rev.* **75,** 425 (1949)
2. M. L. Wiedenbeck, *Phys. Rev.* **68,** 1 (1945)
3. J. M. Hollander, I. Perlman, G. T. Seaborg, *Revs. Mod. Phys.* **25,** 537 (1953)
4. J. Weiss, NUCLEONICS **10,** No. 7, 28 (1950)
5. E. Guth, *Phys. Rev.* **59,** 325 (1941)
6. J. Robertson, A. Sanders, BNL-1330 (1952)

TECHNICAL BRIEFS

• **Elements 99 and 100** have been produced and identified at the University of California's Berkeley cyclotron laboratories. Atomic weights are 247 and 254 respectively. Half-life of element 100 is 3 hr; it was first produced in the MTR reactor. Argonne and Los Alamos Scientific Laboratories have done parallel work.

• **Calutron** at Oak Ridge National Laboratory has separated usable quantities of stable isotopes of ruthenium, palladium, iridium, platinum, and gadolinium. Improved separation was made possible by new ion source that operates at high temperatures.

• **Linear response** of BF_3 chambers used to monitor JEEP reactor at Kjeller, Norway, was extended to 600 kw by placing lead plugs between chambers and reactor core. Previously, saturation caused nonlinearity above 30 kw.

TEST VOLTAGE PROBLEMS 1/100 cps to 10 mc?

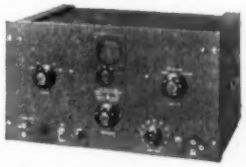
Hewlett-Packard has 17 different oscillator models. Some are highly specialized, others are all-purpose instruments. Almost certainly, there's a model to meet your exact requirements. All are precision instruments of highest quality. All embody the famous RC circuit pioneered by *-hp-*. Check the table below for the oscillator that can help you most. Then write us for complete operating and application details.

Instrument	Primary Uses	Frequency range	Output	Price
-hp- 200AB	Audio tests	20 cps to 40 kc	1 watt 24.5v	$120.00
-hp- 200CD	Audio and ultrasonic tests	5 cps to 600 kc	160 mw 20v open circuit	150.00
-hp- 200H	Carrier current, telephone tests	60 cps to 600 kc	10 mw/1v	350.00
-hp- 200I	Interpolation, frequency measurements	6 cps to 6 kc	100 mw/10v	225.00
-hp- 201B	High quality audio tests	20 cps to 20 kc	3w/42.5v	250.00
-hp- 202A	Low frequency measurements	.01 cps to 1 kc	20 mw/10v	450.00
-hp- 202B	Low frequency measurements	½ cps to 50 kc	100 mw/10v	350.00
-hp- 202D	Low frequency measurements	2 cps to 70 kc	100 mw/10v	275.00
-hp- 204A	Portable, battery operated	2 cps to 20 kc	2.5 mw/5v	175.00
-hp- 205A	High power audio tests	20 cps to 20 kc	5 watts	390.00
-hp- 205AG	High power tests, gain measurements	20 cps to 20 kc	5 watts	425.00
-hp- 205AH	High power supersonic tests	1 kc to 100 kc	5 watts	550.00
-hp- 206A	High quality, high accuracy audio tests	20 cps to 20 kc	+15 dbm	550.00
-hp- 230A	Carrier test oscillator	35 cps to 35 kc	+14 dbm/600 ohms	275.00
-hp- 233A	Carrier test oscillator	50 cps to 500 kc	3w/600 ohms	475.00
-hp- 234A	Carrier test oscillator	160 cps to 160 kc	+14 dbm/600 ohms	300.00
-hp- 650A	Wide range video tests	10 cps to 10 mc	15 mw/3v	475.00

2 OF 17 DIFFERENT *-hp-* OSCILLATORS

-hp- 200CD Audio Oscillator

World standard for electronic or electrical measurements, now redesigned with wider range, lighter weight, smaller size. Use for any lab, field or production problem in subaudio, audio, telephony, carrier, supersonic, telemetering or rf measurement fields. Highest stability, low distortion, constant output, no zero set while operating. With carrying strap, or for rack mounting.



-hp- 202A Low Frequency Function Generator

Compact, convenient, all-purpose source of transient-free voltages between 1/100 cps and 1 kc. Provides distortion-free signals for vibration studies, servo applications, medical and geophysical work and other subsonic problems. Generates sine, square or triangular waves. Output 30 volts balanced or single ended, 1% distortion, constant within 0.2 db.

Data subject to change without notice. Prices f.o.b. factory.

WRITE TODAY FOR COMPLETE INFORMATION

HEWLETT-PACKARD COMPANY

2705-N PAGE MILL ROAD • PALO ALTO, CALIFORNIA, U.S.A.

SALES REPRESENTATIVES IN PRINCIPAL CITIES

INSTRUMENTS FOR COMPLETE COVERAGE

BOOKS

Nuclear Moments

By NORMAN F. RAMSEY (John Wiley and Sons, Inc., New York, 1953, x + 169 pages, $5.00). Reviewed by MORTON HAMERMESH, Argonne National Laboratory, Lemont, Ill.

The investigation of nuclear spins and moments has been one of the most exciting fields of research of the past twenty years. Before the war, it reached its high point in the discovery of the electric quadrupole moment of the deuteron, which showed that nuclear forces are noncentral in character. During this period the methods of optical spectroscopy were for the most part replaced by molecular beam techniques. The techniques were applicable only to gases, so that intermolecular forces did not come into play. For the most part the work of this era was of interest only to nuclear physicists.

The radiofrequency techniques developed during the war led to new methods that enabled us to increase the precision of measurement, and to study nuclear moments in the solid and liquid states. The postwar developments have led in two directions: first, an increase in the armory of technique, which has enabled us to accumulate fairly satisfactory information concerning the moments of ground states of stable nuclei and to make a start on a similar program for radioactive nuclei. This accumulation of precise data has influenced the development of the nuclear shell model and has given a method for checking some of the predictions of the new quantum electrodynamics. Second, the extension of our techniques to solids and liquids enables us to observe by a most sensitive means the effects of neighboring atoms and ions in influencing the electromagnetic field in the neighborhood of a given nucleus. This has led to a whole new technique—the measurement of nuclear moment interactions as a means for studying atomic properties. Thus a field of study which was once of interest only to nuclear physics now has a wide audience in solid state and chemical physics.

For a physicist wanting to become familiar with this field, there has been no up-to-date guide. The book of Kopfermann (1940) concentrated on optical spectroscopy, and gave only a short section to the then new molecular beam magnetic resonance methods. Since 1946, a few survey articles have appeared on special topics, but there has been no over-all picture.

Prof. Ramsey has presented us with a very thorough survey of topics and literature, and an excellent digest of the recent developments. The first four chapters of the present book were originally included in Segrè's "Experimental Nuclear Physics," and have been supplemented by a chapter on applications to chemical and solid state problems.

The very complete bibliography should be of assistance even to specialists in this field. It is regrettable that the book has been held to such small size. Derivations of fundamental formulas are frequently either sketched very briefly or the final result merely cited. Many interesting problems are dismissed with a line of text and a literature reference. The rapid-fire rush through topics loses much of the clarity of the original papers and the enthusiasm and inspiration which many of us have drawn from personal discussions with Ramsey.

The publishers have presented us with an excellent, up-to-date survey. There is still a great need for a textbook, willing to explain at length obvious steps, spending valuable space in qualitative discussions, and pointing to directions for future research.

The Physics of Radiation Therapy

By HAROLD ELFORD JOHNS (Charles C Thomas, Publisher, Springfield, 1953, viii + 286 pages, $8.50). Reviewed by MORTON M. KLIGERMAN, Department of Radiology, Columbia University, New York, New York.

It is most gratifying to read this new volume on radiation physics, which seems to fulfill the needs of the average radiologist practicing radiotherapy better than other texts now available.

The strongest part of the book, and by far the largest portion of it, deals with X-ray and telecurie therapy. However, the part on artificial radioactive isotopes only touches on certain aspects of the use of these materials.

The volume is characterised by the clarity in which formulae are developed, and, with their rapid conversion into graphs and charts, the need for mathematical calculations by the radiologist is held to a minimum. Many of these charts point up the differences between standard deep therapy equipment and the multimillion-volt apparatus now available. By visual comparison with something he already understands, this is a particularly helpful way of removing any mystery about supervoltage which might exist in the minds of the average radiologist.

All of the graphs, charts and illustrations are done in a very attractive manner, which is a credit not only to Dr. Johns, but also to the publisher who has maintained his usual high standards in the makeup of the book.

The author has also shown excellent judgment in the selection of references, both classical and of recent pertinence, which are listed at the end of each chapter and carefully notated in the text. Throughout the book one is conscious of the vast amount of experimental testing which Dr. Johns has performed to verify many of the assumptions on which radiologists have in the past based their procedures.

Depth Dose

The book is practical throughout—a "how to do it" book. It is pointed out, for example, that in the usual therapeutic range an increased depth dose is more economically obtained by increasing the target-skin distance than by increasing the half-value layer of the beam. In addition, it is emphasized that the benefit of employing higher energy X-rays is lost if very large fields are used. However, at very high energies (22 Mev) the depth dose at any level for fields of all sizes is about the same because the scattering is all in the forward direction. An important comment on the usual manner in which the average American radiologist calculates the change in depth dose for changes in target-skin distance is made. Backed by his own experimental work, the author shows the inadequacy of arriving at a satisfactory value by simple use of the inverse-square-law factor. For half-value layers of 1–2 mm of copper, the correction follows Mayneord's formula, $(1 + F)/2$, very well. However, when the half-value layer is raised to 4 mm of copper, the values for the smaller fields do tend to agree with the simple inverse-square-law calculations, while variations of the depth doses with changes in TSD for larger fields follow the Mayneord formula rather closely.

There are several important summaries. One of these, which follows the chapter entitled *The Interaction of X-Rays with a Scattering Medium*, lists five requirements which should be

known before properly controlled radiotherapy can be carried out.

Another summary gives an excellent description of how to calibrate an X-Ray machine and how to calculate the half-value layer. In these descriptions, the author's approach is very practical and gives the details that are often ignored. Following an excellent chapter on the use of multiple X-ray portals, a summary discusses seven fundamental principles that should be followed in the arrangement and direction of radiation fields and the statement of dosage in radiotherapy.

Particular mention should be made about the emphasis placed on the expression of tumor dosage in a specific time period. Although there has been considerable improvement in the recording of dosage in this country, in that the convention of expressing it as tumor dose rather than air dose is being increasingly adopted, there are still many therapists who neglect the importance of indicating the specific time period in which the particular tumor dose was given. A tumor dose in itself is meaningless unless the over-all time in which the dose has been delivered is stated.

Treatment Planning

The chapters on treatment planning, relating both to external radiation and to radium dosage, are excellent. Pertinent examples are offered that are not only commonly encountered, but that illustrate the various considerations that must be given in the majority of patients routinely seen.

The Paterson and Parker type of radium implantations are well illustrated and simply stated. As in the original Paterson-Parker papers, however, the implication is given that the dosage up to within 10% of the uncrossed end of the active length of a planar implant, or within 7½% of the active length of a volume implant, will be ±10% of the stated Paterson-Parker dose for that particular area or volume. This is not the case, as has been clearly shown by Meredith in his excellent volume on the Manchester dosage system. Meredith does show that the dosage rate falls off at a point considerably nearer the center of the implant when the end is uncrossed.

Dr. Johns makes a point at the end of the chapter on radium dosage that deserves restatement. That is the fact that all who are interested in the teaching of physics as it relates to clinical radiation therapy are well aware that

In on the Ground Floor!

When the Manhattan Project went into real production

BEACH-RUSS

Type RP **ROTARY HIGH VACUUM PUMPS** were the pumps used. And ever since then, the dependable performance of these sturdy units has kept them to the fore on nucleonic production and research wherever vacuum entered the picture.

Fast Pump-Down . . .
Low Maintenance

Beach-Russ Type RP Vacuum Pumps take your apparatus down to low vacuum faster than other types of pumps. They operate at exceptionally high mechanical efficiency, and because of their sturdy yet precise construction their operating and maintenance costs are the lowest in the field. They are virtually noiseless and vibrationless due to unusually slow speed of operation.

Beach-Russ Type RP Vacuum Pumps are available in single-stage units in capacities from 20 to 1700 c.f.m. for vacuum up to 10 microns or better. Compound stages are also available.

Write for the RP Pump Bulletin

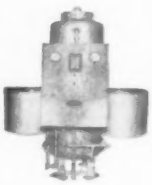
BEACH-RUSS COMPANY
50 Church Street • New York 7, N. Y.
Address Department 66

SUPER HIGH PURITY
WATER
by the trouble-free
magic of ion exchange

No "boil outs"
No "still odors"
No extras
No heat or steam power

Penfield Mono-Column Demineralizer Model M-100. Purity of effluent: less than 2 ppm. Flow rate: 60-90 gph. Dimensions: 1½' x 2' x 7'. Features inspection window that allows easy inspection of crucial middle distribution system.

Penfield Mono-Column Demineralizer Model MA-1000. Purity of effluent: under 1 ppm. Flow rate: 1000-1200 gph. Dimensions: 2' x 5' x 5½'. Features automatic shut-off and signaling devices and fully automatic regeneration system.



Penfield Dual-Column Demineralizer Model UL-60. Purity of effluent: 5 to 10 ppm. Flow rate: 75-100 gph. Dimensions: 2' x 2' x 4½'. Features self-contained stainless steel control cabinet in which regenerant tanks are stored.

READY TO OPERATE ON ARRIVAL!

Available in a wide variety of mono-and multi-column models (flow rates from 10 to 10,000 gph), all Penfield Demineralizers come equipped with regenerant tanks and all necessary gauges, flow meter, conductivity meter, etc. On arrival at site, simply connect the completely "packaged" unit to service lines and start receiving super high purity Penfield demineralized water.

Any model Penfield Demineralizer may be secured with automatic shut-off and signaling devices and a fully automatic regeneration system. Special control systems for the automatic maintenance of the purity of storage tank water supplies also available.

Write for fully descriptive catalog.
PENFIELD M'FG. CO., INC.
19 High School Ave., Meriden, Conn.
Filters · Softeners · Degasifiers · Demineralizers

PENFIELD "PLANNED PURITY" PAYS!

excellent results have been obtained in the past by radiologists who have developed their skills by empiric plans followed by astute clinical observation of the results of their treatments. However, the author correctly states that it is "difficult for such skills to be passed on to others without placing the work on a physical basis." Yet the awareness that certain routine radium treatments which have been based on milligram-hour exposure in the past have validity is expressed in the discussion of the treatment of the cervix. Here it is pointed out that, because geometric factors are similar in the majority of cases, the expression of the dose in milligram-hours is reasonable.

High-Energy Devices

The section of the book dealing with higher energy devices is particularly fine, as one would expect considering the fact that the author has personal experience with a 22-Mev betatron and a cobalt unit. The high degree of collimation of the beam that occurs at higher energies is emphasized. This necessitates the use of compensating filters or a greatly increased target-skin distance. However, since the latter would further increase the already high exit dose, the author believes that the optimum energy for betatron treatment lies somewhere between 20 and 50 Mev. In the Appendix are a wide variety of charts and tables dealing with depth-dose data and isodose distributions for several half-value layers, more than covering the usual therapeutic range.

Perhaps this book should have contained one additional chapter. Protection is dealt with only in a minimal fashion where necessary. A chapter on protection written in the excellent manner of the other chapters in this book would surely be welcomed in the average radiologist's office.

There is no question that Dr. Johns has afforded the hospital physicist and the radiologist an excellent, practical, clearly written text.

BOOKS RECEIVED

Progress in Nuclear Physics, O. R. Frisch, editor, Academic Press, New York (Pergamon Press Ltd., London), 1954, vii + 279 pages, $9.50. (*To be reviewed.*)

Biological Effects of External X and Gamma Radiation, Part I (National Nuclear Energy Series, IV-22B), Raymond E. Zirkle, editor, McGraw-Hill Book Co., Inc., New York, 1954, xxvi + 530 pages, $7.25. (*To be reviewed.*)

Optical Instrumentation (NNES IV-8), G. S. Monk and W. H. McCorkle, editors, McGraw-Hill Book Co., Inc., 1954, xxv + 262 pages, $3.75. (*To be reviewed.*)

Magnetic Cooling (Harvard Monographs in Applied Science, No. 4), by C. G. B. Garrett, Harvard University Press, Cambridge, and John Wiley and Sons, Inc., 1954, x + 110 pages, $4.50. (*To be reviewed.*)

History of the Theories of Aether and Electricity (1900-1926), by Sir Edmund Whittaker, Philosophical Library, New York, 1954, xi + 319 pages, $8.75. Concerned with the tremendous changes in physical concepts that occurred in the first quarter of this century, this book includes the discoveries of special relativity, the older quantum theory, general relativity, matrix mechanics, and wave mechanics.

Nature and the Greeks, by Erwin Schrödinger, Cambridge University Press, New York, 1954, 97 pages, $2.00. In this book, based on lectures delivered at University College, London, in 1948, Dr. Schrödinger points out that by studying Greek scientific thought, errors in present-day scientific thinking may be avoided.

The Physics of the Stratosphere, by R. M. Goody, Cambridge University Press, New York, 1954, x + 187 pages, $5.00. Making use of the great amount of data available through research since the end of the war, this book surveys the present state of knowledge of the physics of the atmosphere from above the weather-forming layers to the base of the ionosphere. Experimental methods and the interpretation of results are emphasized.

Government Contracts Simplified, by George W. Lupton, Jr., William Byrd Press, Inc., Richmond, 1953, xv + 579 pages. This book serves as a compact reference to procurement laws, regulations, decisions, and rulings of interest to Government contractors and subcontractors. AEC contract procurement is briefly discussed, covering negotiated classified contracts, organization, patent rights, and uranium ore bonuses. Monthly supplements are available.

Microwave Spectroscopy, by M. W. P. Strandberg, John Wiley and Sons,

Inc., 1954, vii + 140 pages, $2.50. This book discusses microwave spectroscopy mainly as concerned with rotating molecules. It first considers calculation of rotational quantum energy levels and interpretation of experimental data. The remainder of the book deals with necessary instrumentation.

The Cyclotron, 4th ed., by W. B. Mann, John Wiley and Sons, Inc., New York, 1953, xiv + 118 pages, $2.00. For the most part, this book adheres to the text of the first edition. A chapter has been added to indicate briefly progress in the field since 1940.

Probability and Information Theory, with Applications to Radar, by P. M. Woodward, McGraw-Hill Book Co., Inc., New York (Pergamon Press Ltd., London), 1953, x + 128 pages, $4.50. This book explains how the theory of probability applies to electronics, communication and radar. It is directed toward the reader lacking highly advanced mathematical knowledge.

Experimental Inorganic Chemistry, by W. G. Palmer, Cambridge University Press, New York, 1954, xx + 578 pages, $9.00. This experimental text is introduced with a theoretical discussion of the subject. The experiments outlined in succeeding chapters are prefaced by background information.

Soft Magnetic Materials for Telecommunications, edited by C. E. Richards and A. C. Lynch, Interscience Publishers, Inc. (Pergamon Press Ltd., London), 1953, viii + 346 pages, $9.00. This book is based on papers presented at a conference held at the Post Office Engineering Research Station, England, April, 1952. Discussions cover such topics as studies in permeability, ferromagnetic resonances, hysteresis, pulse characteristics of ferrite magnetic materials, and chemical and physical properties of iron powders.

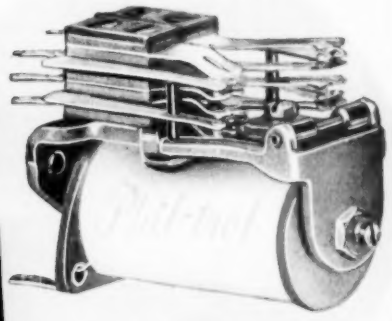
ALSO OF NOTE

Crystal Handbook. This booklet is intended as a reference for the design engineer using crystals. General performance data on many cuts is provided, e.g., temperature coefficients and size factors. A bibliography is included. *James Knights Co., Sandwich, Ill., $1.00.*

Third Annual Report of the National Science Foundation (Year Ending June 30, 1953). Sections of this report in-

When Contact Reliability is most important...

the NEW 8QA MULTI-CONTACT D.C. Phil-trol RELAY



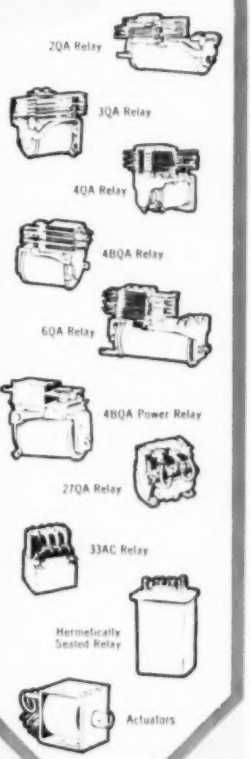
...another addition to the many types of Phil-trol Relays...

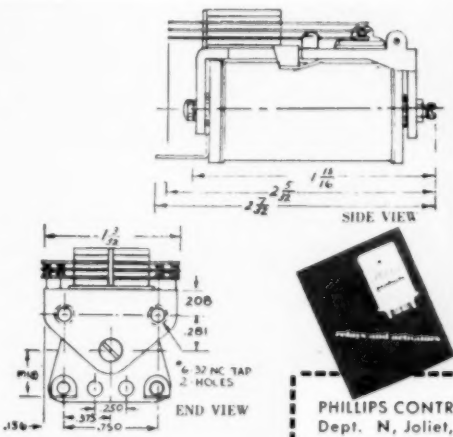
Rugged dependability plus high sensitivity have made this new Phil-trol relay an immediate favorite with engineers and designers. Its compactness and adaptability to a wide range of applications and uses provide new answers to the many complex problems confronting electronic and control engineers.

Unusual features of the new 8QA relay include immediate response; fast closing and opening; contact springs with twin contacts; heavy duty, long-life bronze bearings; light weight.

Like all standard Phil-trol relays, the 8QA is available in a wide range of modifications. Coils may be single or double wound, and equipped with copper slugs or sleeves for slow release or for slow operation.

In all probability, there is a standard Phil-trol relay, or variation, to meet your specific need. Phil-trol engineering experience and design facilities are available to help you solve any new application problem.





Phil-trol

IS THE REGISTERED TRADE MARK OF
PHILLIPS CONTROL CORP.
JOLIET, ILLINOIS
A THOR CORPORATION SUBSIDIARY
OFFICES IN ALL PRINCIPAL CITIES

PHILLIPS CONTROL CORP.,
Dept. N, Joliet, Illinois

Please send me a free copy of the new Phil-Trol Relay and Actuator Catalog. Also, please arrange to have a Phil-Trol Sales Engineer call on me.

Name_____

Company_____

Street_____

City_____ Zone_____ State_____

VERSATILE REMOTE HANDLING

A wide range of hazardous operations are performed safely with the new General Mills Remote Handling Manipulator. The unit offers unusual strength (can handle objects weighing as much as 750 pounds) and superb control (picks up eggs without cracking them).

Continuously variable power and speed controls are easily mastered and eliminate many of the restrictions found in hand-powered or position-controlled mechanisms.

WRITE TODAY for complete details on the Remote Handling Manipulator. We'll be happy to have a representative call if you wish.

Mechanical Division
General Mills Inc.

1620 Central Avenue N.E.
Minneapolis 13, Minn.

- Industrial Instrumentation and Control
- Specialized Precision Computers
- Stratosphere Vehicles

Want more information?
Use post card insert in this issue.

include: *Science and Public Policy, Conferences in Support of Science, Scientific Manpower Studies, Support of Basic Research in the Sciences, Education in the Sciences,* and *Exchange of Scientific Information.* Appendices cover NSF organization, contracts and grants, fellowships, and the financial report for fiscal 1953. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $0.40.*

Recommendations for the Disposal of Carbon-14 Wastes (Cat. No. C13.11:53). The recommendations presented in this 14-page handbook are considered to be conservative with respect to health hazards involved. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $0.15.*

Safe Handling of Cadavers Containing Radioactive Isotopes (Cat. No. C13.11:56). This 15-page handbook gives the minimal precautions to be taken to protect the user and the public. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $0.15.*

Abbott Radioactive Pharmaceuticals Progress Report, Vol. 1, 1953 (Bibliographic Section). Available to radioisotope users, the bibliography gives references to recent work with radioisotopes in fields related to biology and medicine. The subject matter is classified by fields of interest, usually based on a given isotope. References are given to "Nuclear Science Abstracts" and AEC reports. *Abbott Laboratories, North Chicago, Ill.*

Columbia Research News in Engineering and Science, 1954 Annual. This booklet describes informally some of the research completed or under way at Columbia University School of Engineering during the past few months. Among the projects mentioned are the Rainwater-Fitch conception of the atomic nucleus, radiation sterilization studies, and new shielding for the 385-Mev cyclotron. *Columbia Research News, Columbia University Engineering Center, 4 W. 43rd St., New York 36, N. Y.*

Annotated Bibliography in Radiobiology (ANL-5111). The preparation of this reference book, compiled by Sophie V. Stephens and Robert D. Boche, was sponsored by the Argonne National Laboratory and the U. S. Air Force Radiation Laboratory, University of Chicago. Only topics directly

Accurate . . .
Economical . . .
Easy-to-operate . . .

KELEKET
Pocket DOSIMETER

MODEL K-112
AEC #PIC-7A3

Enables X-ray or radioisotope personnel to keep constant check on accumulated X- and gamma radiation exposure. Clips conveniently to pocket. Withstands severe abuse. Only 3½" long. Capacity: 200 mr.

Also high range models to 100 roentgens.

Charged on Keleket K-135 Charging unit.

Write for FREE Bulletin!

KELEKET INSTRUMENT DIV.
266-4 West Fourth St.
Covington, Ky.

STAINLESS STEEL
RIGHT OFF THE SHELF
ALL TYPES OF STAINLESS STEEL FASTENINGS
BOLTS & CAP SCREWS
SOCKET, SET & CAP
NUTS, WASHERS
MACHINE SCREWS
SHEET METAL SCREWS
WOOD SCREWS
PIPE FITTINGS
WRITE, WIRE or PHONE FOR YOUR CATALOG Today
• Class 3 Screws
• AN Drilled Fillister Heads
• Studs, Standard & Special
• AN WASHERS
• Special Screw Machine Products
• TITANIUM BOLTS Now Available: Inquiries Invited
Star Stainless Screws Have Clean, Bright-and-Shiny Heads
Star STAINLESS SCREW CO.
ARmory 4-1240
226 Union Avenue • Paterson 2, N. J.
Direct NEW YORK Tel.: Wisconsin 7-9041

Want more information?
Use post card insert in this issue.

concerned with the biological effects of radiation are considered. *Office of Technical Services, Department of Commerce, Washington 25, D. C., $2.10.*

Tables of 10^x (NBS Applied Mathematics Series 27). This 543-page volume gives antilogarithms to the base 10, or 10^x, in the form of a readily interpolable table for 10-decimal accuracy and a basic radix table for 15-figure accuracy. *Government Printing Office, Washington 25, D. C., $3.50.*

Operation and Repair of Water Facilities in Civil Defense Emergencies (TM 13-2). This manual describes the operations, functions, and requirements of water utilities during civil defense emergencies. Included are discussions of production and distribution of water for essential emergency demands and detection and identification of contaminants. *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., $0.25.*

Bibliography of Selected AEC Reports of Interest to Industry, Part 2 (Chemistry and Chemical Engineering) (TID-3050, pt. 2). This bibliography contains 290 references to nonsecret reports. Availability of each document is indicated. *Office of Technical Services, Department of Commerce, Washington 25, D. C., $0.45.*

Radioisotopes and Small Business. This bulletin, prepared for the Small Business Administration by the AEC, discusses potential small-business applications of radioisotopes for thickness gages, flaw detection, wear measurement, inducing chemical reactions and luminescence, eliminating static, and possible cold sterilization and fast aging of materials. *Small Business Administration, Room 660, Lafayette Building, Washington 25, D. C. (no charge).*

Prospecting with a Counter (RME-4028), by R. J. Wright. This booklet summarizes information on field counters with emphasis on practical problems and a minimum of theory. *Office of Technical Services, Department of Commerce, Washington 25, D. C., $0.25.*

The American Standard Safety Color Code for Marking Physical Hazards and the Identification of Certain Equipment. This revised edition of the war standard includes technical definitions for reproduction of the colors and lists physical samples. *American Standards Association, 70 E. 45 St., New York 17, N. Y., $0.50.*

EKCO Type N529 Scaler for all low activity counting

Ekco Type N529 is a five decade Scaler using 'Dekatron' tubes. It incorporates a stabilized high-voltage supply, an input amplifier and a pulse height discriminator. H.T. and L.T. supplies are available for operating a Geiger-Muller Probe or Scintillation Counter and it requires only the addition of a suitable radiation counter to form a complete counting equipment. The setting up controls are situated behind a hinged door and routine operation is by means of press-button switches.

BRIEF SPECIFICATION

INPUT RESOLUTION
250 Microseconds

INPUT SENSITIVITY
Positive: 5 volts min. to Direct or Probe input.
Negative: 0.1 volt min. to G.M. Input.

AMPLITUDE DISCRIMINATOR
Only pulses exceeding a pre-set amplitude are counted, the acceptance level being set by a potentiometer calibrated from 5-50 volts.

TEST FACILITY
A mains frequency check is included.

H.V. SUPPLY
The output voltage is variable over two ranges, 250-1,000 and 500-2,000 volts, shown by the built-in meter.

MAINS INPUT
110-120 volts and 200-250 volts; 40-60 c.s.

SIZE
20[illegible]" x 11[illegible]" x 12[illegible]"

EKCO *electronics*

Write for the complete catalogue of Ekco Nucleonic and Electronic Equipment, including Scintillation Counters, Scaling Units, Counting Ratemeters, Radiation Monitors, Vibrating Reed Electrometers, Geiger-Muller Tubes, Lead Shielding, Linear Amplifiers, Power Units, Complete Counting Installations, Thickness Gauges.

U.S. Sales & Service:
AMERICAN TRADAIR CORP., CHRYSLER BUILDING, 405 LEXINGTON AVE., NEW YORK 17, N.Y.
Canadian Sales & Service:
CANADIAN AVIATION ELECTRONICS LTD., 6214 COTE DE LIESSE ROAD, MONTREAL, QUEBEC
EKCO ELECTRONICS LTD • EKCO WORKS • SOUTHEND-ON-SEA • ESSEX • ENGLAND

Want more information? Use post card insert in this issue.

NUCLEAR ENGINEERING

Thermodynamic Properties of Liquid Sodium

By JOHN F. LEE
Department of Mechanical Engineering
North Carolina State College
Raleigh, North Carolina

THE IMPORTANCE of liquid sodium as a heat transfer medium, particularly in connection with nuclear reactors, has created a need for tabulated thermodynamic properties so as to permit rapid and convenient solution of design problems.

Although many reliable experimental data are available, they are widely scattered in the literature. Furthermore, the intervals between temperatures for which experimental data are available are so large that either uncertain interpolations or laborious calculations must be made to find properties appropriate to intermediate temperatures.

There is presented here a table of thermodynamic properties of liquid sodium at 5° F temperature intervals over a temperature range that covers all existing and foreseeable practical applications.

Explanation and documentations show how data were obtained or calculated.

Specific heat. Specific heats have been determined experimentally over 97.8–900° C at intervals of 100° (*1, 2*). The experimental data satisfy the following equation through the range of temperatures for which data are available (including the temperatures in the table)

$$c_p = 0.384 - 1.08 \times 10^{-4} T + 3.4 \times 10^{-8} T^2 \quad (1)$$

where T is absolute temperature on the Rankine scale. The specific heat c_p has the units Btu/lb/°F. Effect of pressure on specific heat is negligible over the working range of temperatures and pressures.

Density. Measurements of variation of density with temperature (*3*) generally are accepted as reliable.

Liquid sodium is substantially incompressible over the pressure range encountered in practice; therefore, the effect of pressure on density is neglected. The experimental values of density satisfy the equation

$$\rho = 63.75 - 8.766 \times 10^{-3} T + 9.091 \times 10^{-6} T^2 \quad (2)$$

Density, ρ, is in lb_m/ft^3, where lb_m refers to a mass unit rather than a weight unit.

Coefficient of cubical expansion. The coefficient of cubical expansion, β, is obtained from the defining relationship

$$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_p \quad (3)$$

after substituting from Eq. 2 to yield

$$\beta = \frac{8.766 \times 10^{-3} - 18.182 \times 10^{-6} T}{63.75 - 8.766 \times 10^{-3} T + 0.091 \times 10^{-6} T^2} \quad (4)$$

where β is in reciprocal degrees Rankine. The values obtained from Eq. 4 are in good agreement with others (*4, 5*).

Enthalpy. The differential change of enthalpy is given by the general thermodynamic relationship

$$dh = c_p dT + (1 - T\beta)\frac{dp}{\rho} \quad (5)$$

However, the second term on the right-hand side of this equation is quite negligible for the pressure range encountered in practice. With this simplification and after substituting Eq. 1, the equation is obtained

$$\int_{h_0}^{h} dh = 0.384 \int_{T_0}^{T} dT - \int_{T_0}^{T} 1.08 \times 10^{-4} T dT + 3.4 \times 10^{-8} \int_{T_0}^{T} T dT \quad (6)$$

where the enthalpy, h, is in Btu/lb_m.

The datum state for the table is taken to be solid sodium at the melting temperature and at atmospheric pressure. The melting temperature (208°

Temp. (F)	c_p (Btu·lb$_m^{-1}$ – F^{-1})	$\beta \times 10^6$ R^{-1}	ρ (lb$_m$·ft^{-3})	h (Btu·lb$_m^{-1}$)	s (Btu·lb$_m^{-1}$ – F^{-1})
208	0.3270	149.2	57.93	48.69	0.0729
210	0.3269	149.3	57.92	49.34	0.0740
215	0.3266	149.4	57.87	50.97	0.0764
220	0.3263	149.5	57.83	52.63	0.0788
225	0.3260	149.5	57.79	54.24	0.0810
230	0.3257	149.6	57.74	55.87	0.0834
235	0.3254	149.7	57.70	57.50	0.0858
240	0.3251	149.8	57.66	59.12	0.0881
245	0.3248	149.9	57.61	60.74	0.0904
250	0.3245	150.0	57.57	62.37	0.0927
255	0.3242	150.1	57.53	63.99	0.0949
260	0.3239	150.2	57.48	65.61	0.0970
265	0.3236	150.3	57.44	67.23	0.0993
270	0.3233	150.4	57.40	68.85	0.1015
275	0.3230	150.5	57.36	70.46	0.1037
280	0.3227	150.6	57.31	72.07	0.1059
285	0.3224	150.7	57.27	73.69	0.1082
290	0.3221	150.8	57.23	75.30	0.1104
295	0.3219	150.9	57.18	76.90	0.1127
300	0.3216	151.0	57.14	78.52	0.1148
305	0.3213	151.1	57.09	80.13	0.1168
310	0.3210	151.2	57.05	81.73	0.1188
315	0.3207	151.3	56.01	83.34	0.1208
320	0.3204	151.4	56.97	84.94	0.1232
325	0.3201	151.5	56.92	86.54	0.1251
330	0.3199	151.6	56.88	88.14	0.1273
335	0.3196	151.7	56.83	89.74	0.1294
340	0.3193	151.8	56.79	91.34	0.1315
345	0.3190	151.9	56.75	92.93	0.1335
350	0.3187	152.0	56.71	94.53	0.1355
355	0.3185	152.1	56.66	96.12	0.1375
360	0.3182	152.2	56.62	97.72	0.1395
365	0.3180	152.3	56.58	99.31	0.1415
370	0.3177	152.4	56.53	100.9	0.1434
375	0.3174	152.5	56.49	102.5	0.1454
380	0.3172	152.6	56.44	104.1	0.1473
385	0.3169	152.7	56.40	105.7	0.1491
390	0.3167	152.8	56.36	107.2	0.1509
395	0.3165	152.9	56.32	108.8	0.1527
400	0.3162	153.0	56.28	110.4	0.1544
405	0.3160	153.1	56.23	111.9	0.1562
410	0.3157	153.2	56.19	113.4	0.1580
415	0.3155	153.3	56.15	114.8	0.1597
420	0.3153	153.4	56.10	116.3	0.1613
425	0.3150	153.5	56.06	117.8	0.1630
430	0.3148	153.6	56.02	119.4	0.1648
435	0.3146	153.7	55.97	121.0	0.1667
440	0.3143	153.9	55.93	122.5	0.1685
445	0.3141	154.0	55.88	124.1	0.1703
450	0.3139	154.1	55.85	125.6	0.1722
455	0.3137	154.2	55.81	127.3	0.1739
460	0.3134	154.3	55.77	128.9	0.1756
465	0.3132	154.3	55.72	130.6	0.1773
470	0.3130	154.4	55.68	132.3	0.1790
475	0.3128	154.5	55.64	134.0	0.1806
480	0.3125	154.6	55.60	135.6	0.1823
485	0.3123	154.7	55.55	137.1	0.1839
490	0.3121	154.8	55.51	138.7	0.1855
495	0.3119	154.9	55.47	140.2	0.1871
500	0.3117	155.0	55.42	141.8	0.1887
505	0.3115	155.1	55.38	143.4	0.1903
510	0.3113	155.2	55.34	144.9	0.1919
515	0.3110	155.4	55.29	146.5	0.1933
520	0.3108	155.5	55.25	148.0	0.1949
525	0.3106	155.6	55.21	149.6	0.1965
530	0.3104	155.7	55.16	151.2	0.1981

(*Continued on page 76*)

CANADIAN ATOMIC REACTOR REBUILT...

in operation now

High Specific Activity Pile-Produced Isotopes again available

FACILITIES FOR SPECIAL IRRADIATIONS

RADIOELEMENTS

WRITE FOR NEW CATALOGUE TO:

ATOMIC ENERGY OF CANADA LIMITED
COMMERCIAL PRODUCTS DIVISION
P. O. BOX 93 — OTTAWA, CANADA

Temp. (F)	c_p (Btu·lb$_m^{-1}$ – F^{-1})	$\beta \times 10^6$ R^{-1}	ρ (lb$_m$·ft^{-3})	h (Btu·lb$_m^{-1}$)	s (Btu·lb$_m^{-1}$ – F^{-1})
535	0.3102	155.8	55.12	152.7	0.1996
540	0.3100	155.9	55.08	154.3	0.2012
545	0.3098	156.0	55.03	155.8	0.2027
550	0.3096	156.1	54.99	157.5	0.2042
555	0.3094	156.2	54.95	159.1	0.2058
560	0.3092	156.3	54.91	160.6	0.2073
565	0.3090	156.4	54.86	162.1	0.2088
570	0.3088	156.5	54.82	163.7	0.2103
575	0.3086	156.6	54.77	165.2	0.2119
580	0.3084	156.7	54.73	166.6	0.2134
585	0.3082	156.8	54.69	168.2	0.2149
590	0.3080	156.9	54.65	169.7	0.2165
595	0.3078	157.0	54.61	171.3	0.2180
600	0.3077	157.1	54.56	172.8	0.2194
605	0.3075	157.2	54.52	174.3	0.2210
610	0.3073	157.3	54.48	175.8	0.2224
615	0.3071	157.5	54.43	177.4	0.2238
620	0.3069	157.6	54.39	178.9	0.2253
625	0.3068	157.7	54.35	180.4	0.2266
630	0.3066	157.8	54.31	182.0	0.2281
635	0.3064	157.9	54.36	183.5	0.2295
640	0.3063	158.0	54.32	185.0	0.2309
645	0.3061	158.1	54.28	186.6	0.2322
650	0.3060	158.2	54.23	188.1	0.2335
655	0.3058	158.3	54.19	189.6	0.2350
660	0.3056	158.4	54.15	191.2	0.2363
665	0.3055	158.5	54.00	192.7	0.2376
670	0.3053	158.6	53.96	194.2	0.2390
675	0.3052	158.8	53.92	195.7	0.2403
680	0.3050	158.9	53.87	197.3	0.2417
685	0.3049	159.0	53.83	198.8	0.2430
690	0.3048	159.1	53.79	200.3	0.2443
695	0.3046	159.2	53.74	201.8	0.2457
700	0.3045	159.3	53.70	203.4	0.2470
705	0.3043	159.4	53.66	204.9	0.2483
710	0.3042	159.5	53.62	206.4	0.2496
715	0.3041	159.6	53.57	207.9	0.2509
720	0.3039	159.7	53.53	209.4	0.2522
725	0.3038	159.9	53.49	211.0	0.2535
730	0.3036	160.0	53.45	212.5	0.2548
735	0.3035	160.1	53.41	214.0	0.2561
740	0.3034	160.2	53.36	215.5	0.2574
745	0.3033	160.3	53.32	217.0	0.2586
750	0.3031	160.4	53.28	218.6	0.2599
755	0.3030	160.5	53.23	220.1	0.2612
760	0.3029	160.6	53.19	221.6	0.2624
765	0.3027	160.7	53.15	223.1	0.2637
770	0.3026	160.9	53.11	224.7	0.2650
775	0.3025	161.0	53.06	226.2	0.2662
780	0.3024	161.1	53.02	227.7	0.2674
785	0.3022	161.2	52.98	229.2	0.2686
790	0.3021	161.3	52.93	230.7	0.2698
795	0.3020	161.4	52.89	232.2	0.2710
800	0.3019	161.5	52.85	233.7	0.2727
805	0.3018	161.7	52.81	235.2	0.2734
810	0.3017	161.8	52.76	236.7	0.2745
815	0.3016	161.9	52.72	238.2	0.2757
820	0.3015	162.0	52.68	239.7	0.2768
825	0.3014	162.1	52.64	241.2	0.2779
830	0.3013	162.2	52.59	242.7	0.2791
835	0.3012	162.4	52.55	244.2	0.2803
840	0.3011	162.5	52.51	245.7	0.2814
845	0.3010	162.6	52.47	247.2	0.2826
850	0.3009	162.7	52.42	248.7	0.2838
855	0.3008	162.8	52.38	250.2	0.2849
860	0.3007	162.9	52.33	251.7	0.2860
865	0.3006	163.0	52.29	253.2	0.2872
870	0.3005	163.1	52.25	254.7	0.2884
875	0.3004	163.3	52.21	256.2	0.2895
880	0.3003	163.4	52.18	257.8	0.2908
885	0.3002	163.5	52.13	259.2	0.2919
890	0.3002	163.6	52.09	260.8	0.2930
895	0.3001	163.7	52.04	262.3	0.2941
900	0.3000	163.8	52.00	263.8	0.2952
905	0.2999	164.0	51.96	265.3	0.2964
910	0.2998	164.1	51.92	266.8	0.2975
915	0.2998	164.2	51.87	268.3	0.2986
920	0.2997	164.3	51.83	269.8	0.2997
925	0.2996	164.4	51.78	271.3	0.3007
930	0.2995	164.6	51.74	272.8	0.3018
935	0.2995	164.7	51.70	274.3	0.3029
940	0.2994	164.8	51.66	275.7	0.3039
945	0.2993	164.9	51.61	277.2	0.3050
950	0.2993	165.0	51.57	278.8	0.3060
955	0.2992	165.1	51.54	280.2	0.3071
960	0.2992	165.3	51.48	281.7	0.3081
965	0.2991	165.4	51.44	283.2	0.3092
970	0.2991	165.5	51.40	284.7	0.3102
975	0.2990	165.6	51.36	286.2	0.3112
980	0.2990	165.7	51.32	287.7	0.3122
985	0.2989	165.8	51.27	289.2	0.3132
990	0.2989	166.0	51.23	290.7	0.3142
995	0.2988	166.1	51.19	292.2	0.3153
1000	0.2988	166.2	51.15	293.7	0.3163
1005	0.2987	166.3	51.10	295.2	0.3173
1010	0.2987	166.4	51.06	296.7	0.3184
1015	0.2986	166.6	51.02	298.2	0.3193
1020	0.2986	166.7	50.98	299.7	0.3203
1025	0.2986	166.8	50.93	301.2	0.3214
1030	0.2985	166.9	50.89	302.7	0.3223
1035	0.2985	167.1	50.85	304.1	0.3233
1040	0.2985	167.2	50.81	305.6	0.3243
1045	0.2985	167.3	50.77	307.1	0.3253
1050	0.2984	167.4	50.72	308.6	0.3263
1055	0.2984	167.6	50.68	310.1	0.3272
1060	0.2983	167.7	50.64	311.6	0.3283
1065	0.2983	167.8	50.60	313.1	0.3292
1070	0.2983	167.9	50.55	314.6	0.3303
1075	0.2983	168.0	50.51	316.1	0.3313
1080	0.2983	168.2	50.47	317.6	0.3322
1085	0.2983	168.3	50.43	319.1	0.3332
1090	0.2983	168.4	50.38	320.6	0.3342
1095	0.2983	168.5	50.34	322.0	0.3352
1100	0.2983	168.7	50.30	323.6	0.3362
1105	0.2983	168.8	50.26	325.0	0.3371
1110	0.2982	168.9	50.22	326.5	0.3381
1115	0.2982	169.0	50.17	328.0	0.3390
1120	0.2982	169.2	50.12	329.5	0.3400
1125	0.2982	169.3	50.08	331.0	0.3409
1130	0.2982	169.4	50.04	332.5	0.3418
1135	0.2982	169.5	49.99	334.0	0.3427
1140	0.2982	169.7	49.95	335.5	0.3437
1145	0.2982	169.8	49.91	337.0	0.3446
1150	0.2983	169.9	49.87	338.5	0.3455
1155	0.2983	170.0	49.83	340.0	0.3465
1160	0.2983	170.2	49.78	341.4	0.3475
1165	0.2983	170.3	49.74	342.9	0.3484
1170	0.2983	170.4	49.70	344.4	0.3493
1175	0.2983	170.6	49.66	345.9	0.3500
1180	0.2983	170.7	49.62	347.4	0.3509
1185	0.2984	170.8	49.58	348.9	0.3518
1190	0.2984	170.9	49.54	350.4	0.3528
1195	0.2984	171.0	49.50	351.9	0.3536
1200	0.2984	171.2	49.45	353.4	0.3546
1205	0.2985	171.3	49.41	354.9	0.3555
1210	0.2985	171.4	49.37	356.4	0.3564
1215	0.2985	171.6	49.32	357.9	0.3573
1220	0.2985	171.7	49.28	359.4	0.3583
1225	0.2986	171.8	49.24	360.8	0.3591
1230	0.2986	171.9	49.20	362.3	0.3600
1235	0.2986	172.1	49.16	363.8	0.3610
1240	0.2987	172.2	49.11	365.3	0.3618
1245	0.2987	172.3	49.07	366.8	0.3627
1250	0.2987	172.5	49.03	368.3	0.3636
1255	0.2988	172.6	48.98	369.8	0.3644
1260	0.2988	172.7	48.94	371.3	0.3653
1265	0.2988	172.9	48.90	372.8	0.3662
1270	0.2990	173.0	48.86	374.3	0.3670
1275	0.2990	173.1	48.81	375.8	0.3679
1280	0.2991	173.2	48.77	377.3	0.3687
1285	0.2991	173.4	48.73	378.8	0.3696
1290	0.2991	173.5	48.68	380.3	0.3705
1295	0.2992	173.6	48.64	381.8	0.3713
1300	0.2992	173.8	48.60	383.3	0.3721
1305	0.2993	173.9	48.56	384.8	0.3730
1310	0.2993	174.0	48.52	386.3	0.3739
1315	0.2994	174.2	48.47	387.8	0.3747
1320	0.2994	174.3	48.43	389.2	0.3755
1325	0.2995	174.4	48.39	390.7	0.3763
1330	0.2996	174.6	48.35	392.2	0.3772
1335	0.2997	174.7	48.30	393.7	0.3800
1340	0.2997	174.8	48.26	395.2	0.3880
1345	0.2998	175.0	48.22	396.7	0.3997
1350	0.2999	175.1	48.18	398.2	0.3804
1355	0.3000	175.3	48.13	399.7	0.3813
1360	0.3001	175.4	48.09	401.2	0.3821
1365	0.3002	175.5	48.05	402.7	0.3829
1370	0.3002	175.7	48.01	404.2	0.3838
1375	0.3003	175.8	47.97	405.7	0.3846
1380	0.3004	175.9	47.92	407.2	0.3854
1385	0.3005	176.1	47.88	408.7	0.3862
1390	0.3006	176.2	47.84	410.2	0.3870
1395	0.3007	176.3	47.80	411.8	0.3878
1400	0.3008	176.5	47.76	413.5	0.3887
1405	0.3009	176.6	47.72	414.8	0.3895
1410	0.3010	176.7	47.68	416.3	0.3903
1415	0.3011	176.9	47.63	417.8	0.3911
1420	0.3012	177.0	47.59	419.3	0.3919
1425	0.3013	177.2	47.55	420.8	0.3927
1430	0.3014	177.3	47.51	422.3	0.3935
1435	0.3015	177.4	47.47	423.8	0.3943
1440	0.3016	177.6	47.42	425.3	0.3951
1445	0.3017	177.7	47.38	426.8	0.3959
1450	0.3018	177.8	47.34	428.3	0.3966
1455	0.3019	178.0	47.30	429.8	0.3974
1460	0.3020	178.1	47.26	431.3	0.3982
1465	0.3021	178.3	47.21	432.8	0.3990
1470	0.3022	178.4	47.17	434.4	0.3998
1475	0.3023	178.5	47.13	435.9	0.4005
1480	0.3024	178.7	47.09	437.4	0.4012
1485	0.3025	178.8	47.05	438.9	0.4020
1490	0.3026	179.0	47.01	440.4	0.4027
1495	0.3027	179.1	46.96	441.9	0.4035
1500	0.3029	179.2	46.92	443.4	0.4042

F) and the enthalpy of fusion (48.69 Btu/lb_m) were taken from the literature (*1*).

Entropy. A differential change in entropy is expressed by the general thermodynamic relationship

$$ds = c_p \frac{dT}{T} - \beta \frac{dp}{\rho} \qquad (7)$$

The pressure range encountered in design applications makes the second term on the right-hand side of Eq. 7 negligible. Substituting from Eq. 1, the entropy change is expressed as

$$\int_{s_0}^{s} ds = 0.384 \int_{T_0}^{T} \frac{dT}{T} - 1.08 \times 10^{-4} \int_{T_0}^{T} dT + 3.4 \times 10^{-8} \int_{T_0}^{T} T dT \qquad (8)$$

Entropy is in $Btu/lb_m/°F$. The value for entropy of fusion, s_0, (0.0729 $Btu/lb_m/°F$), was selected from the literature (*1*).

BIBLIOGRAPHY

1. D. C. Ginnings, T. B. Douglas, A. F. Ball, *J. Research Nat. Bur. Standards* **45,** 23 (1950)
2. A. L. Dixon, W. H. Rodebush, *J. Am. Chem. Soc.* **49,** 1162 (1927)
3. C. T. Ewing, H. B. Atkinson, Jr., T. K. Rice, Report P-3287 (Naval Research Laboratory, U. S. Navy Dept., Washington, D. C., 1948)
4. E. Rinck, *Ann. chim. et phys.* **18,** 395 (1932)
5. S. Siegel, S. L. Quimby, *Phys. Rev.* **54,** 76 (1938)

WANTED:

Editors for

NUCLEONICS

---Need men with several years experience in atomic energy field

---or recent graduates with strong college nuclear background

•

Send resume, salary requirements to

The Editor **NUCLEONICS**

330 West 42nd Street

New York 36, N. Y.

NOW!

A REALLY EASY-TO-USE GAS FLOW COUNTER

with maximum efficiency for carbon 14 and other soft betas

Model D47 permits extremely sensitive gas flow techniques . . automatically counts as many as 50 solid or liquid radioactive samples with C-110 sample changer . . automatically scans paper radiochromatograms with C-100 "Actigraph" . . allows manual counting with shielded mount. Model D47 features windowless or thin window (150 micrograms / cm^2) counting in both the geiger or proportional regions . . *is the most versatile gas flow counter ever produced.*

. . ideal for tritium, carbon 14, sulfur 35, etc.

. . detects all soft or hard ionizing radiations

. . converts from windowless to thin window in seconds

. . permits both geiger or proportional counting

. . bubbler and valve adjustments completely eliminated

. . extremely low background

. . *now in production*

Write for the complete details on the new Model D47 gas flow counter.

Nuclear Instrument and Chemical Corporation,
235 West Erie Street, Chicago 10, Illinois

nuclear-chicago

CHICAGO
NEW YORK
LOS ANGELES
DALLAS
HOUSTON
SILVER SPRING, MD.

NEWS

AEC Accepts Duquesne Light Co. Plan; First U. S. Central Station Nuclear Power Plant to Serve Pittsburgh Area

The first U. S. central station nuclear power plant will be built in Pittsburgh. Duquesne Light Co. has been selected to cooperate with AEC and Westinghouse on the project. AEC accepted Duquesne's proposal over eight others because it is "the most favorable to the government."

The private utility's plan calls for the firm to:

1. Furnish a site "on land presently owned by the company in the Greater Pittsburgh area."
2. Contribute $5-million towards the cost of the pressurized water reactor (NU, March '54, p. 75; Dec. '53, p. 70).
3. Finance construction of the electric generating portion of the plant.
4. Operate the reactor and generating portions of the plant and bear all labor costs associated with operation.
5. Pay AEC for the heat used in generating power.

The government will save about $30-million by having Duquesne's assistance, according to an estimate made by AEC Chairman Lewis L. Strauss.

Output of the plant will be fed into the firm's power system and will be marketed to residential and industrial customers. Although "it is not expected that this first plant will produce power at costs competitive with power from conventional fuels," consumers will pay standard rates. The extra production costs will be absorbed by AEC and Duquesne under a contract now being negotiated.

AEC will provide the enriched uranium fuel, and Duquesne will pay 48.3 cents per million Btu of steam for the first year; this cost will increase annually until it reaches 60.3 cents the fifth year. The rates are progressive because the plant will be used for experimental purposes during its early stages of operation; power deliveries will be irregular during that time. According to the Federal Power Commission, coal-produced steam in the Pittsburgh area costs from 33 to 35 cents per million Btu.

Since the formula that AEC's Advisory Committee on Reactor Safeguards normally uses to determine exclusion areas (see box, this page) would require a site with a radius of 5 miles, it is anticipated that, because of the cost of the land involved, this requirement may be modified (e.g., see NU, March '54, p. 57, 75). An illustration of the effect of using this formula was shown by one of the industrial study teams when it reported (NU, June '53, p. 50) that the Safeguards Committee's formula suggested a 70,000-acre site costing $42-million as compared with the study group's estimate of a 2,400-acre site costing $1.5-million. Their reactor would develop 350 Mw of heat.

AEC Cuts Budget Request, Revises Spending Plans

The Atomic Energy Commission last month trimmed its $1,366-million request for new money by $23.9-million. Congress will have the final say on the requests, but AEC wanted to change them before its money hearings began in mid-March.

"New look" for the military is mainly responsible for rejuggling the budget for the fiscal year beginning July 1. Spending for production and weapons facilities in fiscal 1955 would be increased from $74-million to $108-million. Spending cutback would be on operating expenses, which would be trimmed from $1,182-million to $1,051-million.

The revision won't affect the experimental and power reactor program.

Four New Reactors Proposed by AEC

As a result of a request made by the Joint Congressional Committee on Atomic Energy last summer, the Atomic Energy Commission has proposed a five-year program for the development of power reactors (details first reported in NUCLEONICS, Feb. '54, p. 75). In addition to its general research and development work, the AEC has plans for the following:

1. **Pressurized water reactor (PWR).** Now being engineered by Westinghouse to produce at least 60,000 electrical kw (see NU, Mar. '54, p. 75 for further details).

2. **Intermediate-size breeder.** It will be much larger and much more nearly a power-producing, continuously operating reactor than the small experimental breeder in Idaho. The scale-up planned is from 1,400 to 62,500 kw of heat, and from 170 to 15,000 kw of electric power. Temperatures and steam pressure will be increased to values appropriate to a full-scale power breeder. Auxiliaries, such as pumps, heat exchangers, valves, etc., will be of sizes suitable to a full-scale reactor.

3. **Boiling water reactor.** Present plans call for 20,000 kw of heat and 5,000 electrical kw. One step between reactor coolant and turbines will be eliminated by feeding steam directly to turbines.

4. **Homogeneous reactor.** Present homogeneous reactor at Oak Ridge has been producing 1,000 kw of heat. It is being torn down (NU, Mar. '54, p. 75) to be replaced by a 3,000 kw (heat) unit. A further step, already planned, calls for 65,000 kw of heat in a homogeneous reactor that will breed U^{233} in a blanket of thorium surrounding the core.

5. **Sodium reactor experiment (SRE).** This will be a graphite-moderated, sodium-cooled 20,000 kw (heat) unit. No electric power would be produced.

It is expected that North American Aviation Corp., which has designed the reactor, will start work on it shortly.

Boiling Reactor Tests Brighten Safety Picture

Details of the highly significant boiling-water reactor experiments done in Idaho last summer were revealed by the Atomic Energy Commission last

Reactor Exclusion Areas

The reactor exclusion-area formula reported on page 75 of the March issue should have read: radius of exclusion area (in miles) $= 0.01 \sqrt{\text{Power (in kw)}}$. The radical sign was inadvertently omitted.

month. First reported in NUCLEONICS (Dec. '53, p. 71), this work has importance both for reactor safeguard considerations and for nuclear power economics.

AEC had long been worried about what would happen to a water-cooled reactor if the flow of water were cut off. It was feared that if the water supply were cut off or if the temperature of the reactor rose too rapidly boiling would occur with disastrous results.

To study the problem, W. H. Zinn, director of Argonne National Laboratory, built a small reactor in Idaho with the deliberate intention of producing boiling. The reactor was arranged so that the control rods could be suddenly ejected causing the power generated by the chain reaction to go up in a fraction of a second from a few watts to many thousands of watts.

According to AEC, this caused the water to boil—so violently that it was ejected from the reactor in a small geyser. Repeated trials showed that in every case the boiling reduced the power of the reactor so rapidly that no serious damage was done.

The implications for safe operation of such reactors as the "swimming pool" type are apparent. As far as power reactor economics are concerned, considerable saving may be effected by feeding steam generated in the reactor directly to turbines. An intermediate heat transfer step would be eliminated.

U. S. Ore Supply Held Adequate by Mine Owner

In estimating that uranium production in the U. S. had doubled in the last two years, Vernon Pick, a mine owner from Grand Junction, Colorado, said recently that he believed that within a few years domestic mines would be producing all the uranium the country needs.

He made the statements in testifying before a Senate Interior subcommittee investigating supplies of strategic materials.

RAW MATERIALS

• **United States.** Uranium mining leases can now be obtained on public land covered by oil and gas leases. These lands, closed to entry under the mining laws, are now available under AEC leases for uranium mining.

As a result of research being carried

Washington Report

Congress is certain to act this session on at least one and probably more fundamental changes in the Atomic Energy Act.

The Republican leadership has put a priority tag on an amendment permitting exchange of limited weapons-use information with our allies in the North Atlantic Treaty Organization. It will be brought to a vote before the end of the current session.

Congressional action is less certain for two other basic changes in the Act recommended by President Eisenhower in late February (NU, March, p. 74). One of these would encourage domestic industrial development of commercially-feasible nuclear power. The other would permit the exchange of nuclear power data with friendly nations.

In an effort to determine the legislative future of the proposed amendments, NUCLEONICS recently interviewed key members of the Joint Congressional Committee on Atomic Energy. Main conclusions of this preliminary survey:

▶ One or more bills covering the President's general proposals will be introduced by the Joint Committee by mid-April with hearings to be scheduled a few weeks later.

▶ Course of the hearings and of the Committee discussions to follow are hard to predict, but it is probable that proposed amendments reported to the House and Senate will incorporate the general proposals of the President.

▶ If it becomes obvious that the industrial power legislation will unduly delay action on the international aspects of the proposals, they may be separated.

▶ Several key members of the Joint Committee are not convinced of any great sense of urgency as regards the domestic nuclear power proposals.

▶ The House can be counted on to go along with the recommendations of the Joint Committee, but the Senate is much less a sure bet.

Most optimistic of those interviewed was Chairman Sterling Cole of New York who believes the proposals can be handled in a single package. Once the measure is introduced, he thinks it will move along over the legislative hurdles in an orderly manner and brought to a vote in both houses. As far as Cole is concerned, all three proposals are on the "must" list of legislation for this session and he is directing his Committee work accordingly.

Senate Republican Leader William Knowland, who is also a member of the Joint Committee, hopes to get atomic energy legislation out of committee and up for Senate debate by late May or early June. While the Senate supposedly has no "must" list of legislation, Senator Knowland told NUCLEONICS that the atomic energy proposals will have priority when they come to the full Senate for action.

For tactical reasons, the Senate leader doesn't want them to come out during the last minute rush in July as lawmakers are hurrying toward an election year adjournment.

When it comes right down to actual proposals that Congress will vote on, there were marked differences of opinion among the Committee members interviewed. At least three members were not at all convinced that the international proposals should be incorporated in the same measure with industrial development of nuclear power.

Members generally agree that the proposal to share weapons-use information with our NATO allies is the most urgent from a national standpoint. The White House and Defense Department are pushing this one hard. Members interviewed believed this proposal must be approved by Congress even if the other two have to be temporarily shelved.

All members questioned agreed that strict limitations must be placed on the amount and nature of the data to be shared, but they feel, as one member put it, "There is no use keeping from our friends the weapons-use information

(Continued on page 80)

Washington Report (*Continued*)

necessary to our common defense. We know for a certainty that unfriendly nations have this information."

Next in priority comes the proposal for sharing industrial nuclear power information with friendly nations. Main reason given was that the U. S. must exchange some of this information if we are to expect continued access to such rich uranium ore as that furnished by the Belgian Congo.

While all members interviewed favored relaxation of the Atomic Energy Act to encourage wider industrial development of nuclear power, none thought that it was urgent for this year.

Three members foresee considerable controversy in committee over this proposal. Because of the relatively short time left in the present session, they are not certain that the power proposal can be fully dealt with.

Two committee members lean toward the proposition that the power amendments are so far-reaching in nature that extensive revision of the Act is needed. As one of them put it, "We want to be dead sure that changes in the act are so worded that they will accomplish precisely what we are seeking—and not one bit more."

A few members are willing to get down into such details of the power proposals as the procedure for securing patents on nuclear power developments. Three members, for instance, now believe that there should be a ten-year period of non-exclusive patents once the act is relaxed on industrial development. In his message to Congress, President Eisenhower suggested a five-year period for non-exclusive patents in this field. After this preliminary period, patent procedures gradually would be brought into line with standard patent procedure.

•

Continued access to the rich Belgian Congo uranium deposits may hinge on the outcome of the Eisenhower proposal for sharing nuclear power information with friendly nations. High-grade ore from the Congo makes that our cheapest source of supply, and AEC lists it as a "major producer."

Executive agreements with the Belgian government were written in 1944 under stress of war. Britain was a third party. Agreements have been revised from time to time to afford Belgium more financial compensation, but that is not enough to satisfy the power-hungry country. It wants to be able to use its uranium to produce useful industrial energy and it badly needs U. S. know-how to bring that about.

Expiration date of the agreements has never been disclosed by AEC and is hard to get from other sources. Informed but nongovernment sources have put the expiration date between 1954 and 1956. It is of vital importance because Belgium will then be in a position to choke off this source of supply unless we loosen our hold on power reactor information.

Ultimatum of a sort came on this score from Belgian Foreign Minister Van Zeeland in a recent speech in the Chamber of Deputies. It was little noticed by the U. S. press, but a diplomatic cable of the speech received by the State Department is being studied closely in Washington.

Van Zeeland will demand—when the agreements are about to expire or when it appears useful to replace them:

▶"That it be a question of a true association—in English I would say 'partnership' on a plane of complete equality and to all useful ends.

▶"That what I shall call 'the clause of the most favored nation' be assured us within the framework of such an agreement."

Perhaps deliberately, Van Zeeland did not mention the expiration date of these agreements.

He also confirmed what had been reported earlier in NUCLEONICS (Nov. '52, p. 105), that the original agreement had never contemplated the uranium sold to the U. S. being used for anything except the defense of the Western world. The possibility of nonmilitary application had not been envisaged. Because of this, some in AEC opposed wide publicity on industrial nuclear power in this country.

out by the Texas City Chemical Corporation on recovery of uranium from phosphate rock, the firm plans to expand its Texas City, Texas, plant. Construction is expected to begin this fall. Their present plant is the second in the U. S. for the by-product recovery of uranium from phosphate rock; Blockson Chemical Company's plant at Joliet, Ill., was the first. Plants soon will be completed in Florida by International Minerals and Chemicals Corp. and Virginia-Carolina Chemical Corp.

A uranium-ore-treating plant (NU, Feb. '54, p. 76) to be located at Shiprock, N. M., is being built by Western-Knapp for Kerr-McGee Oil Industries under a design and flow sheet worked out by Kerr-McGee in conjunction with AEC. The plant is being built primarily to process carnotite from company-owned mines, but it also will do custom processing.

• **Australia.** A uranium strike believed to be as rich as the Northern Territory's Rum Jungle has been made near Chillagoe, North Queensland. An assay of a sample from one of the outcrops showed 5–10% uranium.

• **Peru.** A joint USAEC-Peruvian team is surveying possible uranium deposits in central and southern areas of the country. No commercially-exploitable discoveries have been discovered as yet in Peru.

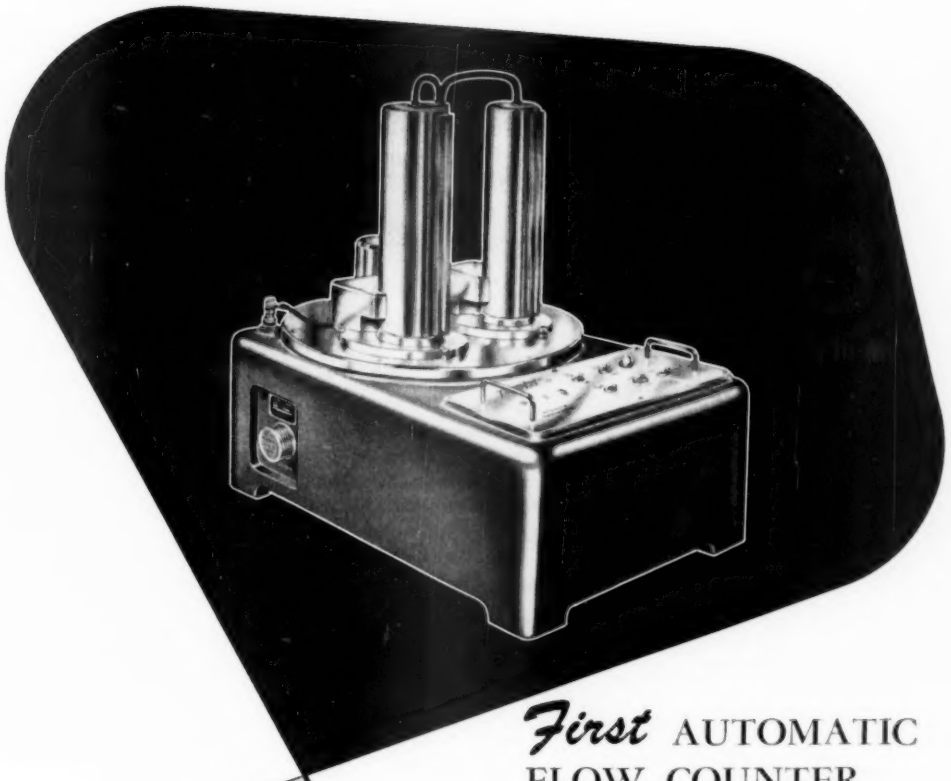
NEWSMAKERS

Walter J. Williams, recently-resigned as deputy general manager of AEC, has been granted a distinguished service award by the Commission. He has become vice president of the Taconite Contracting Corp., and is directing development of iron ores from the Lake Superior region.

Frank R. Ward, formerly with AEC's division of reactor development, is now project coordinator in the reactor and materials department of Westinghouse Electric Corp.'s atomic power division.

E. P. Blizard and **J. L. Fowler** have been appointed associate directors of the physics division at Oak Ridge National Laboratory. Blizard will be in charge of applied reactor physics.

Harvey A. Wagner has been named director of nuclear power development for Detroit Edison Co. **Robert W Hartwell** becomes assistant director of



First AUTOMATIC FLOW COUNTER

Here is the first commercially practicable, completely sealed flow counter for automatic radioassays either in the Geiger or proportional region. The instrument accepts 25 samples of any size up to 1 7/8" D by 5/16" high, with choice of appropriate chamber sizes. Each sample may be counted from one to four times in cyclical order, or the unit may be set so that the cycles are repeated indefinitely. The SC-50 may be used either with the Superscaler or Autoscaler and results are printed on a tape by the Printing Interval Timer, a unit designed *specifically* for nuclear use. *Please request Tracerlog No. 57, for complete details.*

- **Completely automatic Geiger or Proportional counting.**
- **2 pi geometry.**
- **25 samples up to 1 7/8" D in size.**
- **Automatic sample recycling.**
- **Overall accuracy of 1%.**
- **Elapsed time printed for each sample or cumulatively.**

Tracerlab® INC.
130 HIGH ST., BOSTON
2030 WRIGHT AVE., RICHMOND, CAL.

LOS ANGELES • PARIS • CHICAGO • CLEVELAND
WASHINGTON • NEW YORK • HOUSTON • ATLANTA

Proceedings of sessions on

"Business Opportunities in Atomic Energy"

held March 15–16 at the Biltmore Hotel, New York

The full report, covering four half-day and one evening's meetings.

available at

$6 a copy.

•

Reports on individual sessions at $1.50 each:

1. "Uses of Atomic Energy Materials in Industry."

2. "Potential Industrial Applications of Atomic Energy."

3. "Research Facilities Available to Industry."

4. "Government Services to Industry."

5. "Products Required by Atomic Energy Program."

•

Atomic Industrial Forum, Inc.
260 Madison Avenue
New York 16, N. Y.

Sidelights

AEC construction high. During the last half of 1953, AEC's construction program made up 3.35% of the nation's total spending for building.

•

Foster Wheeler-Pioneer Service studying breeder. After considering many types of reactor designs, the Foster Wheeler-Pioneer Service industrial power study team has decided to concentrate its studies on a thermal circulating fuel reactor that breeds U^{233} from thorium. Also considered promising by the group are: fast plutonium breeders with easily-processed fuel, pressurized water reactors with long-life fuel elements, and sodium-graphite reactors with long-life fuel elements.

•

Turkey to build cyclotron. Radioisotopes for medical research will be produced by a $714,200-cyclotron to be built during the next five years at Istanbul University.

•

Cosmic rays to be studied in Australia. The University of Sydney plans to build an underground laboratory for meson study. Protons and electrons from the cosmic rays will be shielded by 50 ft of earth.

•

Safety studies being speeded. According to C. R. McCullough, chairman, AEC Advisory Committee on Reactor Safeguards, "Steps are being taken to arrange for sufficient personnel and organization so that the evaluation of [reactor] problems and hazards will in no way be a stumbling block or a delaying factor in progress of reactors." Some feel that any group set up to handle reactor safeguard problems should be similar in function to the Civil Aeronautics Board.

•

British synchrotron operation limited. Shielding inadequacies caused by space limitations limit operating time of the 1,000-Mev proton synchrotron at Birmingham, England, to about 30 minutes per day. The unit, largest in Europe, was constructed in a building already housing a 25-Mev cyclotron. This was necessary because of building restrictions that existed in England during the early postwar years.

•

Savannah River plant nears completion. About 6,000 of an estimated eventual total operating force of 8,000 were working at AEC's Savannah River plant by the beginning of this year. E. I. du Pont de Nemours & Company is building and operating the plant.

•

Brazil to have first cyclotron in South America. A 6.5-Mev synchrocyclotron built at the University of Chicago, will be used in Rio de Janeiro to produce radioisotopes for medical studies and to train Brazilian physicists in nuclear physics.

•

California has mobile radiological laboratories. Emergency radiological assays of air, water and food supplies in event of atomic attack will be performed by 16 labs mounted on truck bodies. Each unit costs $15,000. California's civil defense office also has let a contract for the construction of 105 radiological monitor trailers.

•

Site chosen for British breeder plant. Dounreay in Caithness, Scotland, has been selected as the site for Britain's second nuclear power plant. It will use a large fast reactor of the breeder type (NU, Dec. '53, p. 70).

•

Smyth reported planning to resign as AEC member. Henry DeWolf Smyth, whose term expires June 30, 1956, is reported to be planning to resign his post as a member of the Atomic Energy Commission. A commissioner since 1949, he reportedly soon will return to Princeton University's physics department. The appointment expiration dates of other commissioners are: Zuckert, '54; Campbell, '55; Murray, '57; and Strauss, '58.

the firm's nuclear power development department.

Donald J. Leehey has been appointed manager of AEC's Santa Fe operations office. He succeeds **Carroll L. Tyler,** who recently resigned.

Frederick W. Brown will assume the duties of director of the National Bureau of Standards, Boulder (Colorado) Laboratories before July 1. The Bureau's Central Radio Propagation Laboratory and the joint NBS-AEC Cryogenics Engineering Laboratory will be under his jurisdiction. The cryogenics laboratory conducts a research program for AEC and the Air Force.

R. E. Zirkle has been appointed chairman of the National Research Council's subcommittee on radiobiology. He succeeds **H. L. Friedell.**

Howard P. Doub, head of the radiology department of Detroit's Henry Ford Hospital, has been elected president of the American College of Radiology.

D. J. Hughes, a Fulbright professor, is lecturing in neutron physics at Oxford's Clarendon Laboratory. He is on leave from Brookhaven National Laboratory.

Robert D. Huntoon has been appointed associate director for physics of the National Bureau of Standards. **Wallace R. Brode, A. T. McPherson,** and **Nicholas E. Golovin** are associate directors for (respectively) chemistry, testing, and administration.

C. J. Borkowski has been appointed director of the new instrumentation and controls division of Oak Ridge National Laboratory. He also will serve as head of instrumentation for nuclear chemistry group. **C. S. Harrill** has been named associate division director, and **E. P. Epler** is now head of the reactor controls department.

MEETINGS

May 17–19: Radiation Research Society Annual Meeting (NU, Feb. '54, p. 79).

July 13–17: Glasgow Conference on Experimental and Theoretical Nuclear Physics (NU, Jan. '54, p. 77).

July 19–24: Harwell Radioisotope Conference (NU, Jan. '54, p. 74).

NOW—simple, high-efficiency measurement of radioactivity of liquid or solid samples with Berkeley complete scintillation counting systems

BERKELEY Model 2001 Decimal Scaler and Model 2250 Vial Scintillation Counter with Model 2254 Lead Shield . . . a typical BERKELEY complete system for laboratory or clinical measurements of gamma radiation.

FEATURES:

SIMPLICITY of installation and operation due to BERKELEY's "complete system" design. Gamma counting eliminates tedius sample preparation.

EXCEPTIONALLY HIGH EFFICIENCY (better than 25% with a 1 ml sample of Iodine 131).

LOW COST . . . total cost of complete system pictured above is $1,155.00, f.o.b. factory.

DIRECT-READING DIGITAL PRESENTATION reduces error.

FLEXIBILITY . . . BERKELEY offers a wide range of scintillation counters, shields, count rate meters, counting rate computers, recorders and other accessories for use with BERKELEY counting systems. Your initial installation may thus be readily and economically expanded as required.

BERKELEY Offers a Complete Line of Nuclear Instruments, Accessories!

- Decimal Scalers
- Portable Scalers
- Count Rate Meters
- Counting Rate Computers
- Survey Instruments, Monitors
- Scintillation Counters
- Decimal Counting Units
- Double Pulse Generators
- Accessories: Automatic Timers, Clocks, GM Tubes, Probe Assemblies, Recorders, Lead Shields, Planchets, Absorbers.

Berkeley *division*
BECKMAN INSTRUMENTS INC.
2200 WRIGHT AVE., RICHMOND, CALIF.

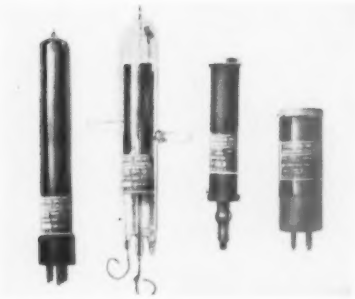
Dept. E-4 2200 Wright Ave., Richmond, Calif. M-29

Please send catalog, prices on
Berkeley Scintillation Systems ☐
Complete Nuclear Line ☐

Name
Title
Address
City State

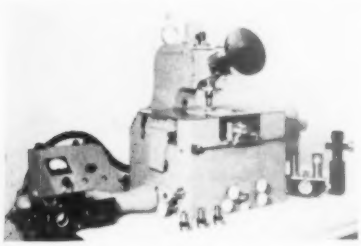
Want more information? Use post card insert in this issue.

PRODUCTS AND MATERIALS



G-M Counters

Five counters are available for monitoring, radiochemical analysis, and radioassaying. The model 12 bismuth-wall counter is said to have an efficiency of $\sim 3\frac{1}{2}$ times that of standard G-M tubes for I^{131}; size is 1 × 8 in.; envelope is glass or brass. The model 1HC internal helix counter is designed for assays of liquid samples; internal thin-wall glass helix permits counting hard betas and gammas; helix volume is 1 cm^3. The model DE-35 mica end window counter, with window thickness of 1.4–2 mg/cm^2 or 3–4 mg cm^2 is halogen-quenched tube for survey instruments; size is $\frac{25}{32} \times 7\frac{5}{64}$ in.; two models available with operating voltage of 700 and 900 volts. The model DE-14 mica end window, neon-filled, halogen-quenched, alpha and beta counter has window thickness of 1.4–2 mg/cm^2; size is $1\frac{3}{32} \times 4\frac{11}{32}$ in.; available operating voltages are 700 and 900 volts. The model DE-34, beta-counting version of DE-14, has window thickness of 3–4 mg/cm^2. *The Atomic Center for Instruments & Equipment, Inc., 489 Fifth Ave., New York 17, N. Y.* (P-1)



Nuclear Scattering Microscope

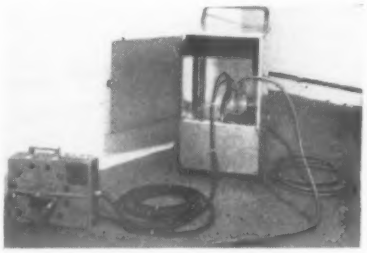
The model MS-2 microscope is suitable for use in the nuclear-track emulsion technique. A system of compensating blades is said to eliminate stage noise in motion along the X and Z axes. Y motion can be blocked for measurements along the X axis. Nuclear-track plates can be moved a preselected distance for scattering measurements. Scanning area is 50 × 50 mm. Independent magnetic and pneumatic rotation systems permit rotation at any point of the plate. Available objectives traverse over 2,000 microns of emulsion. Built-in illumination system produces no thermal effects at the microscope. Michelson-type interferometer checks linear displacement of X and Z drives. *Koristka Optical Co., Milan, Italy (distributed by Scientific Specialties Corp., Snow and Union Sts., Boston 35, Mass.).* (P-2)

Radioactivity Absorbers

The model C-101 set of radioactivity absorbers consists of 24 lead and aluminum disks mounted in uniform plastic rings. These calibrated absorbers are $1\frac{7}{8}$ in. in diameter and $\frac{3}{16}$ in. thick. Their weight ranges from 1.7 to 6,720 mg/cm^2. *Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill.* (P-3)

Radiochemicals

These C^{14}- tagged compounds include: the amino acids, ethionine (5-C^{14}), alpha-amino butyric acid (1-C^{14}) and (3-C^{14}), dihydroxyphenylalanine (2-C^{14}); the purine, caffeine (1-methyl C^{14}); and the physiological amine tyramine (8-C^{14}) and (w-C^{14}). These compounds are available with specific activities of 0.5–2.0 millicuries/millimole. *Bio-Rad Laboratories, 800 Delaware St., Berkeley 9, Calif.* (P-4)



Radiographic Equipment

The PES (Panoramic Exposure Shield), for use in Co^{60} radiography, is available in two models, model 202 for 2,000 millicuries and model 402 for 4,000 mc. They consist of a lead-filled steel source shield, flexible and adjustable (up to 21 ft) source exposure tube, and 25-ft control cable. The three units are in a cabinet mounted on wheels. Dimensions are 41 in. high, 19 in. wide and 21 in. deep. Shipping weights are 500 lb for the 202 and 600 lb for the 402. *Technical Operations, Inc., 6 Schaufer Court, Arlington, Mass.* (P-5)

Shielding Material

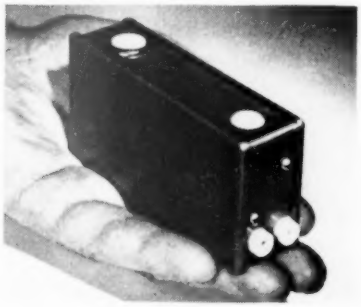
Boronol, polyethylene compounded with boron-bearing materials, is available as radiation shielding material in sheet, rod, block, and fabricated form. Moldings over 300 lb can be supplied. If desired, arrangements can be made to machine completely these moldings to close tolerances. Fabrication facilities are available that allow incorporation of moldings into finished equipment. *Allied Resinous Products, Inc., Box 461, Conneaut, Ohio.* (P-6)

Radioactivity Shield

The Raysist storage and transportation vault for radioactive materials is made of Ferrolum-lead-clad steel. The lead cladding is chemically bonded to the steel and is said not to separate unless

Want more information? Use post card insert in this issue.

melted off at 621° F. The cap is secured through a screw-type design further stabilized by a locking device; removable lead plug is provided. For resistance to high heat, vaults are designed with insulated steel jacket. Vaults are available in all sizes. *Knapp Mills, Inc., 23-15 Borden Ave., Long Island City, N. Y.* (P-7)

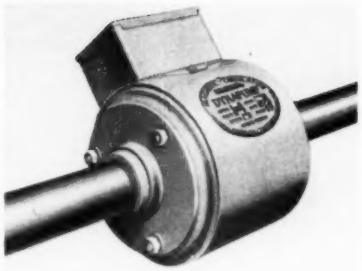


CD G-M Counter

The model RA-1U3 G-M counter is completely self-contained, providing continuous or intermittent service. Used in conjunction with earphones, it is designed as a civil defense aid. Made of heavy gage steel, it weighs 11 oz. *Micro Specialties Co., Cam-Mac Div., 1834 University Ave., Berkeley 7, Calif.* (P-8)

Decade Shunt

The model 2008 decade plugs onto a Keithley electrometer, converting it to a direct-reading micromicroammeter. The shunt carries ten current ranges in decade values, permitting full-scale current measurements of 2×10^{-12} to 10^{-3} amperes. Absolute accuracy is within 6% of lower-scale readings, and 3% of full-scale readings. Time constant is 10 sec on 10^{-12} ranges and 2 sec on other ranges. *Keithley Instruments, 3868 Carnegie Ave., Cleveland 15, Ohio.* (P-9)

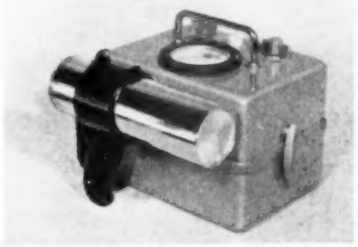


Magnetic Pump

The Dynapump stainless-steel magnetic pump, for circulator applications, has no shaft seal or motor bearings to require servicing. Pump gives 24-ft heads. It accepts interchangeable flanges of $^3/_4$–$1^1/_2$ in. *Fostoria Pressed Steel Corp., Fostoria, Ohio.* (P-10)

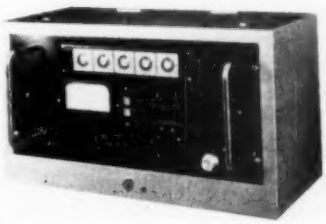
Scintillation Phosphors

Crystalline and plastic phosphors are available for counting alphas, betas, gammas, neutrons, protons, and X-rays. NaI(Tl) in sealed aluminum capsule with optical glass window, with 1 in.^{3}, 2 cm^3 or 1 cm^3 crystals, is suitable for direct mounting on flat-faced photomultiplier tubes. Stilbene is supplied in rough single crystal or machined and polished. Zinc sulphide is available in perspex ($1^1/_8$-in. diameter by $^5/_8$ in.) or as silver-activated powder or fabricated alpha screens. Tetraphenyl butadiene in polystyrene is available in bulk, or machined and polished to specified dimensions. Cadmium sulfide is supplied as $6 \times 2 \times 2$ or $2 \times 1 \times 1$ mm needle crystals. *Isotope Developments Ltd., Finsbury Pavement House, 120 Moorgate, London E.C. 2, Eng.* (P-11)



Radiation Monitor

The model CAX37P scintillation survey meter provides eight ranges, giving full-scale readings from 0.05 mr/hr to 500 r/hr. Standard instrument is furnished with $1^1/_2 \times ^3/_4$ in. NaI(Tl) crystal hermetically sealed in Al container; ZnS, anthracene and other phosphors, plasticized and mounted in snap-on holders, are available. Multiplier tube is RCA 5819, or equivalent DuMont tube if requested; dynode voltage divider network is mounted in probe. Over-all sensitivity adjustment is provided for calibrating energy-dependent crystals; eight controls are provided for adjusting individual sensitivity of the ranges and ninth control for adjusting dark-current bucking circuit. *R-C Scientific Instrument Co., Inc., 307 Culver Blvd., Playa del Rey, Calif.* (P-12)



Decade Scaler

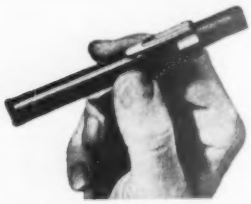
The type N529 five-decade scaler uses Dekatron tubes. It incorporates a stabilized high-voltage supply, input amplifier, and pulse-height discriminator; supplies are available for operating G-M probe unit or scintillation counter. Input resolution time is 250 μsec. *Ekco Electronics Ltd., Southend-on-sea, Essex, England.* (P-13)

Water Pump

The model 4300 bronze pump, with scoop rotor and rubber roller-type vanes, is designed for continuous water recirculation through the use of sealed, permanently lubricated ball bearings. A continuous 5,000-hr test with water at 40 lb is said to have caused no measurable wear in the Hy-Car rubber rollers or the pump case. The pump

Want more information? Use post card insert in this issue.

For Measuring
RADIOACTIVE EMISSION



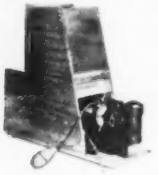
Gamma Ray Pocket Dosimeter

A personnel protection instrument to measure cumulative exposure to x- or gamma rays. The cylindrical case contains an ionization chamber and a quartz fiber electrometer. Optical system enables position of the fiber to be read easily upon a 40-division translucent scale. Standard range 0-200 milliroentgens. Size 4¾" x ½" dia.

Other CAMBRIDGE Instruments

LINDEMANN-RYERSON ELECTROMETER

has high sensitivity and good stability. Does not require leveling. When reading, the upper end of the needle is observed on a scale illuminated through a window in bottom of case. Size 8.3 x 6.5 x 3.5 cm. Weight 0.17 kg.



CAMBRIDGE PORTABLE PROJECTION VIEWER—This new Projection Viewer, used in conjunction with the Lindemann-Ryerson Electrometer, facilitates observation of the deflection of the electrometer pointer. A beam of light from a lamp in front of the case projects the image of the index pointer onto a mirror in the rear of the case. This image, magnified 100 times, is then reflected upon a translucent screen, clearly visible in the front and upper part of the case. This screen is 120 mm. long and is divided into 120 divisions numbered 60-0-60. The pointer is zeroed by grounding the electrometer by means of a rubber bulb.

"CHANG and ENG" FAST NEUTRON DETECTOR follows closely original design of U. S. Atomic Energy Commission. Consists of twin ionization chambers, Lindemann Electrometer, reading microscope and dry cells. Self-contained.

PRECISION IONIZATION METER (Failla Design). A complete instrument for null methods of radioactivity measurement where background radiation effects must be eliminated. Operated from A.C. outlet.

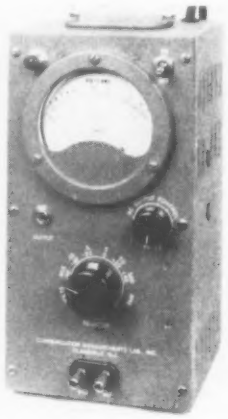
Send for complete information

CAMBRIDGE INSTRUMENT CO., INC.

Pioneer Manufacturers of Precision Instruments

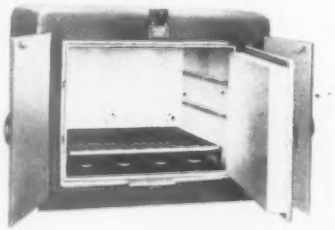
3774 Grand Central Terminal, N. Y. 17, N. Y.

delivers 7 gal/min at 50 lb pressure and 1,750 rpm. Pressure range is 0–75 lb/in.² *Hypro Engineering, Inc., Dept. KP, 404 N. Washington Ave., Minneapolis 1, Minn.* (P-14)



Vacuum-Tube Voltmeter

The model 1520 vacuum-tube voltmeter covers a range of 500 μv to 500 volts (rms) over a frequency range of 15 cycles to 250 kc. Meter is calibrated in a-c voltage and decibels. Meter-scale range is 0.5–5.0 volts. Decibel range is −5 to +17 db, based on zero db equalling 1 mw in 600 ohms. *Communication Measurements Laboratory, Inc., 350 Leland Ave., Plainfield, N. J.* (P-15)



Portable Oven

The model HT-2 portable oven, thermostatically controlled, has a range of 300–1,000° F. Double doors are provided. Drip pan, lower shelf, pilot light and outside reading thermometer are standard equipment; additional shelves and automatic timer are available. Heater is Inconel-sheathed sealed tubular element. Inside dimensions are 22 in. wide × 18 in. deep × 14 in. high. Other models are available to 1,200° F. *Grieve-Hendry Co., Inc., 1811–19 W. Lake St., Chicago 12, Ill.* (P-16)

A-C, D-C Electrical Meter

The Universal 88 meter has 88 overlapping ranges in current and voltage so that all readings can be taken on the upper half of the scale. Available are 24 ranges in d-c current from 200 μa, full scale, to 1.5 amperes; 28 ranges in d-c voltage from 20 mv, full scale, to 750 volts; 16 ranges in a-c current from 10 ma, full scale, to 3 amperes; and 20 ranges in a-c volts from 0.5 volt, full scale, to 750 volts. *Sensitive Research Instrument Corp., 9–11 Elm Ave., Mount Vernon, N. Y.* (P-17)

Litz Cable

This Litz cable, for applications of high voltage in the 20–400 kc region, is wound on dielectric plastic core. Core diameters are ⅛ to 2 in. Typical cables have included copper conductors of 33 and 38 gage laid on the core with a spiral of three turns per foot. Maximum of 125 multiconductor strands can be applied. Conductors of Nylon-enamel insulated wire can be made individually continuous to rigid specification requirements. Polyethylene, Mylar, or other plastic cores are utilized. *U. S. Plastic Rope Co., 2581 Spring St., Redwood City 10, Calif.* (P-18)

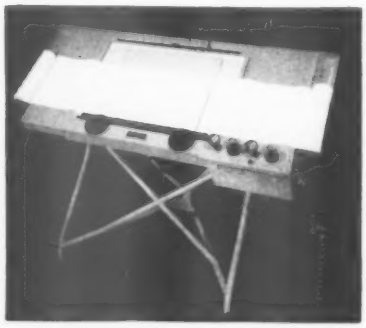
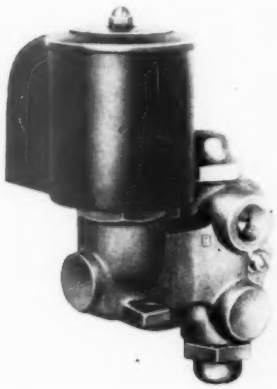


Chart Reader

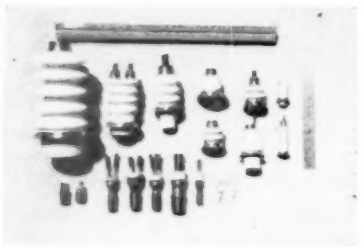
The Contact Telereader is claimed to measure film and oscillograph records many times faster than is possible by

manual methods. Measurements are made by means of rapid cross-wire motion with an accuracy of 0.01 in. The reader handles single-sheet or roll records of any length and any width up to 18 in. Measurements can be made between a trace and base line, between two traces or peak-to-peak on oscillatory traces. It handles orthogonal records and records with curved coordinates. Linear or nonlinear calibrations can be applied electronically or graphically. In combination with programming units, readout can be typewritten, perforated tape, or punched cards. *Telecomputing Corp., Burbank, Calif.* (P-19)



Solenoid Valves

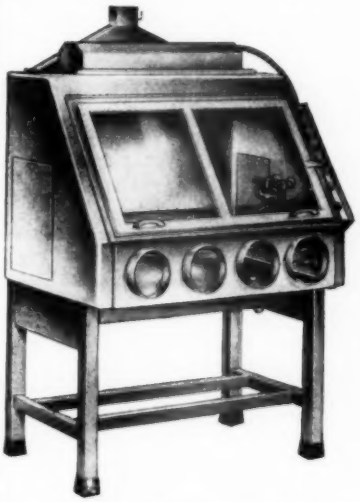
These three-way solenoid valves, with steel or stainless-steel bodies, are designed to handle gases or liquids usually corrosive to bronze, brass and cast iron. With high-temperature coils, these valves handle gases to 450° F. Valves are available with water-tight and explosion-proof solenoid enclosures or standard enclosures. Pipe size is 1 in.; five port orifices are $\frac{1}{8}$–$\frac{3}{8}$ in. Maximum pressure is 1,000 lb/in.^{2} *Automatic Switch Co., Orange, N. J.* (P-20)



High-Temperature Terminals

These hermetic high-temperature terminals are produced by brazing metal members to high-alumina ceramic. A number are said to have been used at

This new Kewaunee Safety Hood No. 3635 gives your laboratory personnel 5-way protection:



- PROTECTION IN HANDLING RADIOACTIVE MATERIAL
- PROTECTION AGAINST BACTERIA
- PROTECTION AGAINST VIRUSES
- PROTECTION AGAINST TOXIC MATERIALS
- PROTECTION AGAINST FUMES

- Hood constructed entirely of 14 ga. stainless steel, with ¼" thick Pyrex glass viewing panels and fluorescent light.
- When gloveport panel is removed for fume hood work, uniform velocity of 100 ft. per minute is provided through the opening.
- Interior of hood and all welds ground and polished to satin finish for easy cleaning and decontamination.
- Hose connections for air, gas, vacuum, hot and cold water and 110v electric current. Integral cup-sink and swivel spout water fixture. Neoprene gaskets throughout.
- Blower, sterilamp, receptacle and fluorescent light indicators and switches conveniently located outside.
- Exterior of hood and steel base finished with acid resistant enamel.
- 1-piece welded stainless steel transition duct section. Provision is made for attachment of vestibule or entrance chamber to either end of hood.
- Outside measurements: Height (with stand) 6 ft. 6 in.; width 2 ft. 8 in.; length 4 ft. Hoods also available in 5 and 6 ft. lengths.

Write for descriptive literature and drawing on the Kewaunee 3635 Safety Hood

We also manufacture all types of Stainless Steel Equipment for radioactive laboratories. Laboratory tables, sinks, etc. for all types of laboratories.

Manufacturers of wood and metal laboratory equipment

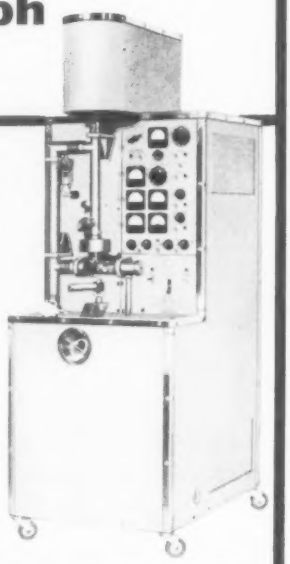
Representatives in principal cities

Kewaunee Mfg. Co.
J. A. Campbell, President
5083 S. Center Street • Adrian, Mich.

Want more information? Use post card insert in this issue.

high-speed microoscillograph

flat response to ten thousand megacycles



Central Research Laboratories' High-Speed Microoscillograph makes single-sweep oscillograms of three simultaneous phenomena at frequencies up to 10,000 megacycles. With a high sensitivity of 0.2 volt per trace width, this is the instrument of choice for recording phenomena occuring in time intervals of 10^{-8} to 10^{-10} second.

Electromagnetically focussed beams, 0.01 millimeter in diameter, write directly on a photographic plate inserted into the vacuum chamber through a vacuum lock. One plate holds 27 oscillograms with no overlapping. A complete cycle of photographic plate changing and reestablishing operating vacuum takes less than 5 minutes.

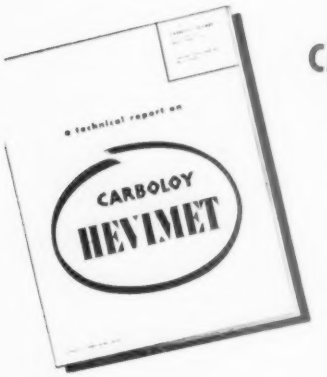
6 individually-shielded deflecting systems are provided: 3 signal, 3 time. Signal deflecting systems are of traveling-wave type with a nominal impedance of 50 ohms.

The instrument complete with all necessary pumps, gages, and power supply circuits weighs 700 pounds on a caster-mounted chassis of 26" x 36" x 76".

For complete information, write to

Dept. 201—Red Wing, Minnesota

Central Research laboratories, inc.



Hevimet is available in two grades, in any size and shape.

FREE TECHNICAL REPORT

CARBOLOY® HEVIMET FOR RADIOACTIVE SCREENING

Get the latest technical information on Carboloy Hevimet – the ideal tungsten shield for radioactive screening.

Hevimet provides 40% more gamma ray protection than lead. The technical report contains radiation comparison charts for Hevimet and lead absorbers for broad and narrow beam Radium and Co^{60} sources.

Hevimet is machinable, dimensionally stable, and of relatively high tensile strength. Applications include: containers for radioactive materials, source wheels, X-ray machines and oil well logging equipment. Send coupon, today.

"Carboloy" is the trademark for products of the Carboloy Department of General Electric Company

CARBOLOY

DEPARTMENT OF GENERAL ELECTRIC COMPANY
11130 E. 8 Mile Street, Detroit 32, Michigan

Send me a free copy of new Hevimet Technical Report RV-3

Name _____ Position _____

Company _____

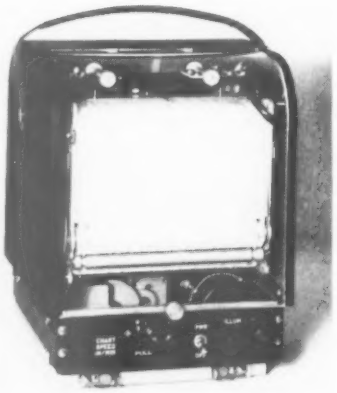
Address _____

City _____ Zone _____ State _____

350° C. Bond rupture is claimed not to have occurred when the terminals were plunged from liquid at −50° C to liquid at +225° C for many cycles. Terminals have been made up to 3 in. diameter × 6 in. *Ceramaseal Co., Box 25, New Lebanon Center, N. Y.* (P-21)

Gas Flowmeter

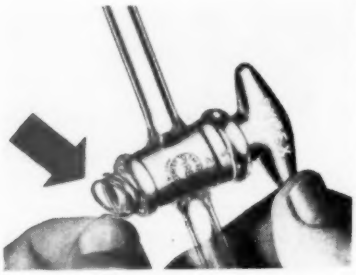
The model 30 gas flowmeter consists of a differential pressure gage across a linear pressure-drop flow element. It is operable at up to 20 psig for measuring gas flow and down to $\frac{1}{2}$ psia for vacuum service. Neither the flow element nor indicator require levelling; the instrument is designed for semi-remote applications. The meter may be operated from −60° to +180° F. Full-scale flow ranges are available from 0.003 to 30 ft^3/min for most gases. *National Instrument Laboratories, Inc., 6108 Rhode Island Ave., Riverdale, Md.* (P-22)



Recording Milliammeter

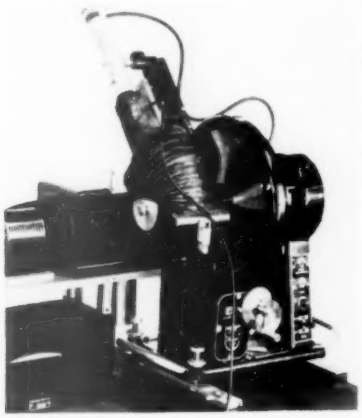
This recording milliammeter uses standard curvilinear chart paper and provides two independent channels and four selective chart speeds. Magnetic-fluid-clutch meter movements permit small instrument size (15$\frac{1}{2}$ lb). Paper is standard 6-in. translucent chart in 100-ft rolls. Chart speeds are 12

in./hr to 12 in./min. Frequency response ranges through 15 cps with an accuracy of ±5% from d-c through 6 cps. Sensitivity is 0.45 in./100 μa, with a linear recording range to 500 μa. Unidirectional recording is possible to 1 ma. *Texas Instruments, Inc., 6000 Lemmon Ave., Dallas 9, Texas.* (P-23)



Pyrex Stopcocks

In this line of Pyrex stopcocks, a spring-type clamp replaces the rubber washer formerly used. Tension is said to remain positive longer; minor adjustments may be made. The retainer is also claimed to minimize the danger of freezing. *Corning Glass Works, Corning, N. Y.* (P-24)



Spectrograph Attachment

This attachment for the Norelco X-ray spectrograph permits use of helium instead of air in the X-ray beam path. The air path previously limited the lower spectrum range to calcium; helium extends the range down to sulfur. Results obtained indicate a probable sensitivity limit of 0.02% for sulfur, with comparable limits for other elements in the same atomic range. Accessory equipment includes housing that encloses X-ray tube and provides compartment for specimen holder, plate-type collimator with mounting,

SPECIALISTS in DESIGN and PRODUCTION of NUCLEAR INSTRUMENTS

One of the precision SCALERS by TMC

The SG-1A Scaler features all-electronic scaling, with no mechanical register needed. Seven pre-set count ranges are available, from 100 to 100,000. An anti-overloading amplifier with Schmitt discriminator provides 20 millivolt sensitivity for scintillation and alpha proportional counting. A built-in timer provides pre-set times for a few seconds to one hour with 0.2 second accuracy. The SG-1A has an exceptionally stable, 300 to 2500 volt power supply, controlled by a multi-turn dial with lock. Price (FOB New Haven, Conn.) is only $995.

TMC also manufactures the SG-2A with high voltage power supply, pre-set time, scale of 100 to 1000, and with instantaneous reset register.

RATEMETER RM–1A

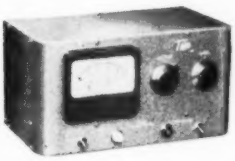
Wide range—100 to 100,000 C.P.M.
Choice of 1%, 3%, or 10% probable error
High accuracy—1.5% of full scale
Schmitt discriminator, —50 +150 volts
Built-in alarm circuit

TMC

PULSE AMPLIFIER AP-1A

Anti-overloading design
300 microvolts, 10 millivolts, or
300 millivolts sensitivities; noise-free.
Ideal for C^{14} proportional counting and scintillation counting
High stability

TMC



POWER SUPPLIES HV-1A and HV-2A

300 to 2500 volts, positive or negative (HV-1A)
1000 to 5000 volts positive (HV-2A)
Excellent stability; low noise
High reset accuracy
Multi-turn dial and lock

All the instruments shown above are presently available from stock and are only a few of the nuclear instruments manufactured by TMC. Write for literature covering our other fine instruments such as the GP-1A Pulse Generator, the SG-3A Research Counter, and the SA-1A Multi-Channel Pulse Height Analyzer.

Look to TMC for quality instruments to give long dependable service in your laboratory.

TMC

TECHNICAL MEASUREMENT CORPORATION

New Haven, Conn. **Box 1947**

MAGNETIC-AMPLIFIER CIRCUITS

Just Published!

Treats the fundamental principles and applications of magnetic amplifiers from the simplest, most practical viewpoint possible. A source of detailed information, it develops logically the various kinds of basic and more complex circuit arrangements. Uses descriptive and graphical methods to give quantitative and qualitative interpretation of essential facts. Classified according to circuit functions, material includes information on modern magnetic servo amplifiers used in high performance servomechanisms, magnetic amplifiers of the balance detector type, improved techniques in analyzing the transient response of magnetic amplifiers. By W. A. Geyger, U. S. Naval Ord. Lab. 277 pp., 135 illus., $6.00

Introduction to NUCLEAR ENGINEERING

Just Published!

Gives an understanding of the unique engineering problems encountered in the nuclear energy field. Includes nuclear fission, the nuclear chain reactor, reactor theory, radiation shielding, reactor materials, and reactor control. Also covers separation of stable isotopes, chemical processing of radioactive materials, remote handling equipment. Goes into special engineering problems. Gives numerous examples. By Richard Stephenson, Consulting Engineer. 387 pp., 135 illus., $8.00

BIOLOGICAL EFFECTS of EXTERNAL X and GAMMA RADIATION

National Nuclear Energy Series

Vol. 22B, Div. IV, Plutonium Project Board

Just Published!

Covers the investigations of the National Cancer Institute of the effects of continuous gamma irradiation on life span, weight, blood picture, and breeding behavior of small laboratory mammals, and of the induced changes in organs and tissues, including tumor production. Some other subjects covered: the mortality of rabbits after X irradiation; hematological effects on rabbits with pre-existing anemia; basic studies of X-ray action on enzymes and tissue metabolism. Edited by Raymond E. Zirkle, Prof. of Radiobiology, U. of Chicago. 530 pp., 210 illus., 60 tables, $7.25.

SEE THESE BOOKS 10 DAYS FREE

McGraw-Hill Book Co., 330 W. 42 St., NYC 36

Send me book(s) checked below for 10 days' examination on approval. In 10 days I will remit for book(s) I keep, plus a few cents for delivery, and return unwanted book(s) postpaid. (We pay for delivery if you remit with this coupon; same return privilege.)

- ☐ Geyger—**Magnetic-amplifier Circuits**—$6.00
- ☐ Stephenson—**Nuclear Engineering**—$8.00
- ☐ Zirkle—**NNES—Biological Effects of External X and Gamma Radiation**—$7.25

(Print)

Name.....

Address.....

City..... Zone.... State.....

Company.....

Position..... NU-4

This offer applies to U. S. only

and accordion-shaped rubber jacket that encloses analyzing crystal and connects specimen compartment to G-M tube-collimator assembly. *North American Philips Co., Inc., Research & Control Instruments Div., 750 S. Fulton Ave., Mount Vernon, N. Y.* (P-25)

Pirani Vacuum Gage

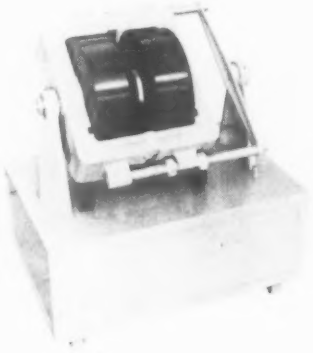
The model 516 Pirani vacuum gage operates in the range 1.0–0.001 mm Hg. Low-impedance power rectifier eliminates need for voltage adjustments during operation. One meter is used for voltage adjustment and pressure reading. Incorporation of outgassing circuitry on the pressure-range selector switch permits outgassing at any pressure without danger to the filament. Gage cords up to 100 ft long may be used. *National Research Corp., 70 Memorial Dr., Cambridge, Mass.* (P-26)

Metallic Bellows

These welded-diaphragm metallic bellows are claimed to have longer life since the welded construction allows better distribution of flexing. Standard-type bellows consists of series of male expansion elements; nesting type comprises series of nesting male and female expansion elements for extreme flexibility. Standard type is produced in 50 sizes, 1–36.0 in., i. d.; nesting type is in 27 sizes, 0.687–7.375 in., i. d. Both types are available in stainless steel, Monel and Inconel. *Titeflex, Inc., 500 Frelinghuysen Ave., Newark 5, N. J.* (P-27)

D-C Power Supply

The model 302 d-c power supply provides two outputs: 150–350 volts at 0–80 ma, positive or negative grounded to chassis, regulation $< \pm 0.05\%$ against line and load variations within specifications; 0–150 volts at 0–5 ma, positive internally connected to negative of output no. 1, regulation better than $\pm 1.0\%$ against line variations only. Ripple is <3 mv; ambient temperature range is 0–40° C. Several units may be paralleled and operated from a single control. A-C output is 6.3 volts at 5 amperes, unregulated. *Allied International, Inc., Allied Engineering Div., Connecticut & Richards Aves., S. Norwalk, Conn.* (P-28)



Laboratory Electromagnet

The 6-in. model V-4007 laboratory electromagnet has changeable pole caps for uniform or high field work. Adjustable gap provides gap range of $\frac{1}{4}$–6 in. Dolly mount permits mobility without loss of rigidity. Magnet yoke angle can be changed for various working positions. Model V-2200 regulated power supply is available for operation of the magnet; it has provi-

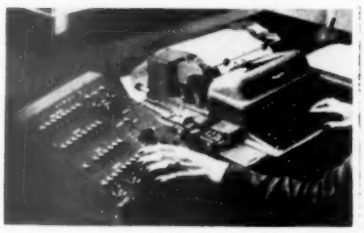
sions for field modulating and nuclear-magnetic-resonance field-controlling. *Varian Associates, Special Products Sales Dept., Palo Alto, Calif.* (P-29)

Digital Time Meter

The model D705 digital time-interval meter measures intervals of 40 μsec to 1 sec with accuracy of ±10 μsec. Polarity is selectable. Three channels are provided for start, stop, and start-stop. Sensitivity is 1 volt with rise times greater than 1 volt/μsec. Frequency stability is ±1 part in 100,000. *Digital Instrument Co., Inc., Box 1345, Coral Gables, Fla.* (P-30)

Germanium Diodes

These six crystal diodes are of germanium point-contact type and utilize sealed-in-glass construction. General-purpose type 1N34-A is for low-power rectification. Large-signal type 1N38-A is useful in electronic computers and clamping circuits. High-back-resistance type 1N54-A is for use in clipping and d-c restorer circuits, high-impedance high-voltage probes, and high-impedance detector circuits. Large-signal type 1N55-A has a high peak inverse voltage rating. High-conduction type 1N56-A has exceptionally low dynamic impedance. Type 1N58-A is similar to type 1N55-A but has lower peak inverse voltage rating. *Radio Corp. of America, Tube Dept., Harrison, N. J.* (P-31)



Digital Computer

The ALWAC is a low-cost, general-purpose electronic digital computer.

You Specified...

Wave Length Independency

A Stable, Drift-Free Circuit

Ruggedness—Yet Light Weight

Convenience in Use

YOU GET ALL OF THESE SPECIFIED FEATURES AND MORE—IN A

New GAMMA DOSE RATE SURVEY METER,

BUILT BY THE PIONEER MANUFACTURER OF RADIATION INSTRUMENTS

- THREE RANGES OF SENSITIVITY:
  MODEL 592—0-10, 0-100, 0-1000 mr/hour.
  MODEL 592A—0-5, 0-50, 0-500 r/hour.
- Two-stage D.C. amplifier circuit with 100% negative feedback.
- Factory calibrated on x-ray and radium or Cobalt 60.
- Accuracy conservatively rated at 10% of true dose over an energy range of 50 Kev to 1.3 Mev.
- Plug-in ion chamber for interchangeability.
- Ion chamber for model 592A may be used in 592.
- Hermetically sealed ion chamber in model 592 is unaffected by environmental conditions of temperature, humidity or pressure.
- Single hi-meg and electrometer tube sealed in the ion chamber.
- Two controls . . . An on-off-range switch and zero set.
- Well balanced with handle on top.
- Rugged, fiber-glass reinforced case easily decontaminated . . . meets military requirements.
- Weighs only 4¾ pounds.

For Further Details . . . Write for Form 3021

MEDICAL INSTRUMENTS DIVISION

The Victoreen Instrument Co.

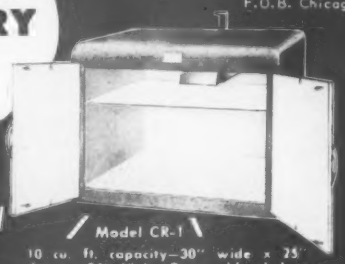
5806 HOUGH AVENUE • CLEVELAND 3, OHIO

ELECTRIC OVEN • Only $89.50

F.O.B. Chicago

GRIEVE-HENDRY PORTABLE ELECTRIC OVEN

FOR PRODUCTION OR LABORATORY USE



Model CR-1

10 cu. ft. capacity—30" wide x 25" deep x 24" high. Removable shelves and drip pan.

Quick Quotations — Prompt Delivery — Reasonable Prices — on Ovens made to your specifications.

Portable. Adjustable temperature control to 225°F. Fan driven forced air circulation. Uniform temperature throughout. Plugs into any 110V wall outlet—no special wiring required. Can be used in a group or bank.

Other standard models with temperature ranges to 1000°F available. Write for literature.

GRIEVE-HENDRY CO., INC.

Export Dept., 306 W. Washington Blvd., Chicago 6, Illinois

1823 W. Lake St., Chicago 12, Ill.

Examine Free!

INTRODUCTION TO NUCLEAR ENGINEERING

by Raymond L. Murray

Just published! Here is a new book that bridges the gap between standard engineering and physics principles and actual applications of nuclear engineering. It is based on the author's experience at the Oak Ridge Atomic Laboratories and on his participation in the development of the only peacetime reactor in the U. S. at North Carolina State College. Every phase of nuclear engineering from fission and the chain reaction to nuclear propulsion of aircraft, submarines and rockets is described. Contents include: Atomic and Nuclear Physics. Neutrons. Fission and the Chain Reaction. The Separation of Isotopes. The Water Boiler. Reactor Start-Up and Operation. Materials of Reactor Construction. Detectors and Control Instruments. Principles of Heat Transfer and Fluid Flow. Plutonium Production. Nuclear Reactor Principles. Design of Gas-Cooled Enriched Uranium Reactor. Radiation Hazards. Shielding. Radioactive Waste Disposal. Neutron Experiments. Uses of Radioactive and Stable Isotopes. Electrical Power from Fissionable Fuel. Design of Liquid-Metal Cooled Normal-Uranium Reactor. Nuclear Propulsion of Aircraft, Submarines, and Rockets.

FREE 10-DAY TRIAL. Mail coupon below for free-examination copy. After ten days, remit $9.35 or return book and owe nothing.

Prentice-Hall, Inc., Dept. M-NU-454
70 Fifth Ave., New York 11, N. Y.

Send me for free examination a copy of INTRODUCTION TO NUCLEAR ENGINEERING. At the end of ten days I will either remit $9.35 plus few cents postage, or return the book and owe nothing.

Name_____

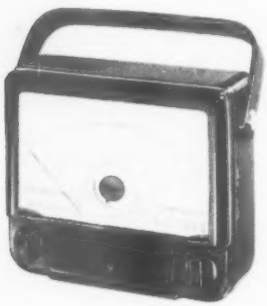
Address_____

City_____ Zone_____ State_____

A copy of this quick-reading, 8-page booklet is yours for the asking. It contains many facts on the benefits derived from your business paper and tips on how to read more profitably. Write for the "WHY and HOW booklet."

McGraw-Hill Publishing Company, Room 2710, 330 West 42nd St., New York 36, N. Y.

with internally programmed magnetic drum. It consists of an arithmetic unit, memory unit, control unit, and input-output sections. Rotating magnetic drum memory has 2,048-word main storage capacity. Automatic graph-following and graph-plotting equipment can be provided for input and output. *Logistics Research, Inc., Redondo Beach, Calif.* (P-32)



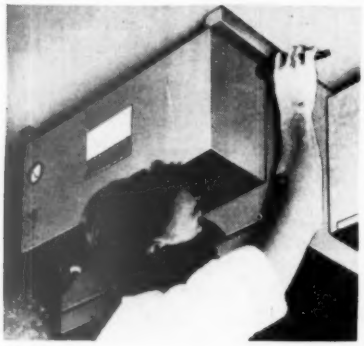
Volt-Ohm-Milliammeter

The model 262 volt-ohm-milliammeter provides 33 ranges with accuracy of 3%, d-c, and 5%, a-c, of full-scale deflection. D-C Voltage ranges are 0–1.6 to 0–4,000 volts with 20,000 ohms/volt sensitivity. A-C voltage ranges are 0–3 to 0–800 volts with 5,000 ohms/volt sensitivity. A-F output voltage ranges are 0–3 to 0–160 volts with 0.1 μf internal series capacitor. Volume level ranges are −12–+11 to +22.5–+45.5 decibels with zero db power level of 0.001 watt in 600 ohms. D-C resistance ranges are 0–500 ohms to 0–50 megohms. D-C current ranges are 0–80 μa to 0–16 amperes with 267 mv maximum drop. *Simpson Electric Co., 5200 W. Kinzie St., Chicago 44, Ill.* (P-33)

Amplifier

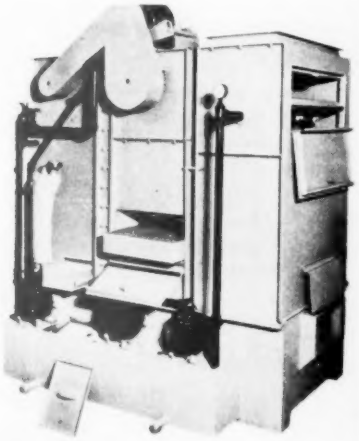
The model TAA-16B amplifier determines standing-wave ratios or compares any two demodulated signals. Dual input channels have sufficient gain for full-scale meter deflection with <2-μv input. Amplifier may be used broadband at 500–5,000 cycles or sharply tuned over this range. For

bolometer use, internal voltage source is supplied with adjustable current for either input. Meter scale is calibrated in SWR and db of SWR with a precision attenuator permitting db of SWR readings up to 50 db. *Browning Laboratories, Inc., 750 Main St., Winchester, Mass.* (P-34)



Air Cleaner

The Precipitron is available in a ceiling-suspended model electrostatic air cleaner. It is claimed to remove 90% of all airborne dust and pollen. Model PH-122 handles 1,000–1,200 ft^3 of air per minute; the floor model PH-242 handles 2,000–2,400 ft^3/min. Electronic tubes are guaranteed for one year. Water and drain line connections for washing away accumulated dirt are provided. The cleaners may be adapted to forced-air heating or air-conditioning plant. *Westinghouse Electric Corp., Air Conditioning Div., Dept. T-556, 200 Readville St., Hyde Park, Boston 36, Mass.* (P-35)

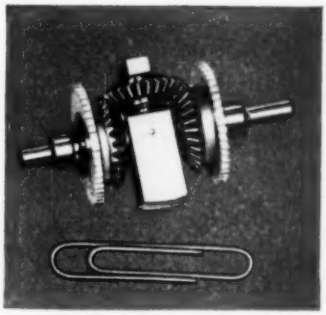


Air Conditioner

The series 5700 apparatus is a combined air conditioner and air dryer. A

the NEW

1/8" MECHANICAL DIFFERENTIAL from FORD INSTRUMENT COMPANY



- Operates in working circle of 1.000" max. diameter
- Lost motion does not exceed 12 mins.
- High sensitivity
- Stainless steel throughout; resistance to wear and corrosion
- Uses Zerol bevel gears.
- Weight, with typical end gears, is less than one ounce

The 1/8" differential is the latest and smallest addition to the Ford Instrument line of single spider gear differentials. Engineered to highest military and commercial standards, this highly reliable unit provides extreme accuracy in additive and subtractive operations, while functioning with minimum friction and backlash.

WRITE FOR FULL DETAILS

Fully illustrated data sheet gives performance curves and characteristics. Please address Dept. NU.

FORD INSTRUMENT COMPANY
31-10 THOMSON AVENUE
LONG ISLAND CITY, N. Y.

IN MAKING RESEARCH PAY

You may need an experienced team of engineers, chemists, physicists and mathematicians. NDA, the senior nuclear engineering firm in the United States, is applying the new skills of atomic technology to industrial problems. Our services for government and industry include:

research in new sources of energy
industrial uses of radiation
design of nuclear reactors
process instrumentation
information handling and computing techniques
intense heat transfer applications
research using high pressures
and similar high performance engineering

NDA_

NUCLEAR DEVELOPMENT ASSOCIATES, INC.
80 Grand Street, White Plains, New York
WHite Plains 8-5800

Please send me NDA Information Booklet N-2

Name_____
Organization_____
Address_____

THE NMC PROPORTIONAL COUNTER CONVERTER

Ideal for Soft Betas

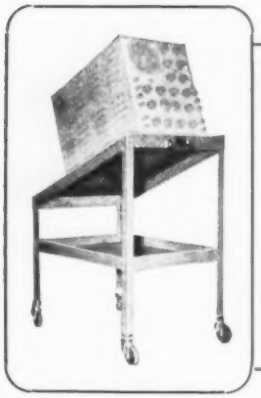
• No window absorption • 2 π geometry • Full yield α counting • Differentiates between α and β • Negligible resolution loss • Adapts any scaler to proportional counting • Rapid decontamination

MODEL PCC-10
$385.00
F. O. B. INDIANAPOLIS

•

FREE CATALOG
Catalog N-8 covers NMC's complete line of nuclear instruments.

NMC
Foremost Manufacturer of Proportional Counters
Nuclear Measurements Corp.
2460 N. ARLINGTON AVE. • INDIANAPOLIS 18, IND.



SCOPE DOLLY MODEL 1

- Convenient Height and Viewing Angle
- Adjustable to Hold Portable Scopes
- Ball Bearing Swivel Rubber Tired Casters
- Lightweight Aluminum Construction
- Recommended by Laboratories Wherever Used

$38.50
F. O. B. Louisville, Ky.

TECHNICAL SERVICE CORP.
1404 West Market Street Louisville 3, Kentucky

MOVING?

If you are moving (or have moved), tell us about it, won't you? Your copies of NUCLEONICS will not follow you unless we have your new address immediately. Make sure you don't miss a single important issue . . . and help us make the correction as speedily as possible by giving us your old address, too

NUCLEONICS
Circulation Dept.
330 W. 42nd St., New York 36, N. Y.

spray of Hygrol moisture-absorbing liquid fixes the output air's relative humidity and temperature according to the spray's temperature and absorbent concentration. Since air temperature and moisture content are established as separate functions, control is maintained by thermostats. Units range in size from 1,000 to 5,300 ft³ of air per minute. *Niagara Blower Co., 405 Lexington Ave., New York 17, N. Y.* (P-36)

INDUSTRY NOTES

▶ **Computer Instruments Co.** is the new name of the former Micromax Co., 1964 Utica Ave., Brooklyn.

▶ **Consolidated Engineering Corp.,** 300 N. Sierra Madre Villa, Pasadena 8, Calif., has created a wholly-owned subsidiary, Electro Data Corp., which will handle engineering, manufacturing and sales of electronic digital computers. Consolidated has also established a systems design and development division, which will study a customer's requirements and design and deliver information-processing systems.

▶ **Vibro-Ceramics Corp.,** Metuchen, N. J., offers a materials testing service utilizing an ultrasonic method.

▶ **Tracerlab, Inc.,** 130 High St., Boston 10, Mass., has completed a project involving tracing a radioisotope-tagged scraper through a 652-mile oil line. The scrapers were used in the 30-in. crude oil line from Superior, Wis., to Sarnia, Ontario.

▶ **Arthur D. Little, Inc.,** 30 Memorial Dr., Cambridge, Mass., has appointed Warren C. Lothrop vice president in charge of the research and development division.

▶ **High-Voltage Engineering Corp.,** Cambridge, Mass., has completed a 50-Mev microwave linear accelerator for the Argonne Cancer Research Hospital of the University of Chicago. The design is based on research done at the Stanford University Microwave Laboratory. Work was supported by the AEC.

LITERATURE AVAILABLE

Hydraulic cylinders. Bulletin 53 describes series J hydraulic cylinders. *Hydro-Line Mfg. Co., 5737 Pike Rd., Rockford, Ill.* (L-1)

Overload relays. Bulletin 5101A gives specifications and applications

senior chemists
metallurgists
physicists

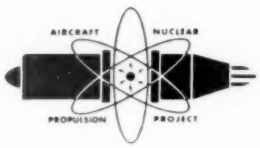
OPPORTUNITIES
with
AIRCRAFT NUCLEAR PROPULSION DEPARTMENT
of General Electric

The challenge of atomic power . . . the stability and resources of General Electric combine to provide far-reaching opportunities in this great new field.

Work will involve correlation and analysis of radiation effects on materials. Primary interest in the interpretation of data rather than experimental approach is desirable.

PhD degree or equivalent in Physical Chemistry, Physical Metallurgy, or Physics is essential, with 8 to 10 years' experience in work involving radiation effects.

Please send resume to:
Department 0-9, Technical Personnel



GENERAL ELECTRIC

Aircraft Nuclear Propulsion Department
Atomic Products Division

P.O. BOX 132 CINCINNATI 15, OHIO

INDEX TO ADVERTISERS
April 1954

Atomic Energy of Canada Ltd. 75
Atomic Industrial Forum, Inc. 82
Atomic Instrument Company . . 3rd Cover
Beach-Russ Company 69
Berkeley Div., Beckman Instruments, Inc. 83
Burndept, Ltd. 60
Cambridge Instrument Co., Inc. 86
Carboloy Department of General Electric Company 88
Central Research Laboratories, Inc. . . 88
Consolidated Vacuum Corporation . . . . . 2nd Cover
Ekco Electronics, Ltd. 73
Ford Instrument Co. 93
General Electric Co. 6
General Mills, Inc., Industrial Div. . . 72
Grieve-Hendry Co., Inc. 92
Hewlett-Packard Co. 67
Keleket Instrument Div. 72
Kewaunee Mfg. Co. 87
Kinney Mfg. Div., New York Air Brake Co. 3
Kollmorgen Optical Corporation 57
Mallory & Co., Inc., P. R. 61
Martin Company, Glenn L. 5
McGraw-Hill Book Co. 90
Minneapolis-Honeywell Regulator Co., Industrial Division 2
Mycalex Corporation of America . . . 96
Nuclear Development Associates, Inc. . 93
Nuclear Instrument & Chemical Corp. . 77
Nuclear Measurements Corp. 94
Penberthy Instrument Co. 95
Penfield Mfg. Co., Inc. 70
Philips Gloeilampenfabrieken, N. V. . 65
Phillips Control Corp. 71
Prentice-Hall, Inc. 92
Raytheon Manufacturing Company . . . . . 4th Cover
Searchlight Section 95
Star Stainless Screw Co. 72
Technical Measurement Corporation . 89
Technical Service Corp. 94
Titeflex, Inc. 63
Tracerlab, Inc. 81
Victoreen Instrument Co. 91
Weston Electrical Instrument Corp. . . 4
Where to Buy 95

•

SEARCHLIGHT SECTION
(Classified Advertising)
H. E. Hilty, Mgr.

EMPLOYMENT 95

This index is published as a convenience to the readers. Every care is taken to make it accurate, but NUCLEONICS assumes no responsibility for errors or omissions.

USED—RECONDITIONED
NUCLEONIC EQUIPMENT
Keleket Alpha Scalers and Chambers
Telemark Neutron Monitors
Dosimeters, Speed Counters etc.
quality at substantial savings
ENGINEERING ASSOCIATES
434 Patterson Road Dayton 9, Ohio

POSITION VACANT

OPENINGS IN Guided Missile and Rocket Development Program. Need qualified personnel in the fields of engineering, mathematics, physics, chemistry, ballistics. Opportunity for self expression and extension of present scientific knowledge. Write or send application on Standard Form 57, which can be obtained at your Post Office, to Commanding General, Redstone Arsenal, Huntsville, Alabama: Attn: Luther Adams, Civilian Personnel Division.

New "SEARCHLIGHT" Advertisements
received by April 9th will appear in the May issue subject to limitations of space.
Classified Advertising Division
NUCLEONICS
300 West 42nd St. New York 36, N. Y.

WHERE TO BUY

Larger Sizes Now Available
HI-D* LEAD GLASS WINDOWS
For use in steel, lead, and concrete walls.
*Trademark
PENBERTHY INSTRUMENT CO.
666-8 Adams St. Seattle 8, Wn.

When the job demands precision

dimensional accuracy

– there's no substitute for MYCALEX® glass-bonded mica insulation

The coil form shown in this RCA-Victor precision tank coil is injection-molded of MYCALEX 410 glass-bonded mica insulation. The coil, operated at approximately 1000 rpm, is subject to high start and stop stresses. The winding contacts a traveling disc and operates at high potential and high frequency. MYCALEX was selected for this application after careful evaluation. The extreme dimensional accuracy, attainable with MYCALEX glass-bonded mica – the unique ceramoplastic – insures perfect contacting and at the same time eliminates balance problems. High dimensional accuracy also affords absolute uniformity of parts, facilitating assembly and replacement. The excellent dielectric properties of MYCALEX insure efficient electrical performance.

– and MYCALEX offers

OUTSTANDING SUPERIORITY

in almost every other category!

- IMMUNITY TO REPEATED ARCING
- PERMANENT DIMENSIONAL STABILITY
- VERY LOW LOSS FACTOR
- EXCELLENT DIELECTRIC STRENGTH
- ZERO MOISTURE ABSORPTION
- UNLIMITED DESIGN FLEXIBILITY

Note: MYCALEX 410 glass-bonded mica, described above, is an exclusive formulation of, and manufactured only by, the Mycalex Corporation of America. It meets all the requirements for Grade L-4B under Joint Army-Navy Specifications JAN-1-10.

For similar economical solutions to your problems, phone or write J. H. DuBois, Vice President-Engineering at the Clifton, N. J. address below.

SINCE 1919 MYCALEX® THE INSULATOR

MYCALEX CORPORATION OF AMERICA

World's largest manufacturer of glass-bonded mica products

Executive Offices: 30 Rockefeller Plaza, New York 20, N. Y.

ADDRESS INQUIRIES TO—

General Offices and Plant: 118 Clifton Blvd., Clifton, N. J.

of hydraulic-magnetic overload relays. *Heinemann Electric Co., Trenton 2, N. J.* (L-2)

Radioactive waste disposal. Circular describes procedure for shipping wastes to New York for disposal. *Radiologica. Service Co., 92-15 172nd St., Jamaica 33, N. Y.* (L-3)

Plastic tubing. Bulletin 3025-A describes $^1/_4$ and $^3/_8$ in., o. d., fittings. *Imperial Brass Mfg. Co., 1200 W. Harrison St., Chicago 7, Ill.* (L-4)

Accelerometers. Bulletin A104 describes units for measurements up to 1,200 cps and 200 g. *Gulton Mfg. Corp., Metuchen, N. J.* (L-5)

Labeled chemicals. Price list available for C^{14}-labeled inorganic and organic compounds. *Nuclear Instrument and Chemical Corp., 223 W. Erie St., Chicago, Ill.* (L-6)

Oil exploration. Reprints available: "Radioactivity in Geophysical Oil Search," "Now They're Hunting Oil with Atomic 'Guns,'" "Atomic Tools Seen Opening New Era in Geological Exploration." *Radiac Co., Inc., Geo-Nuclear Explorations Div., 489 Fifth Ave., New York 17, N. Y.* (L-7)

Laboratory planning. "Better Laboratory Planning" covers industrial, college, hospital, and research and development laboratories. *Scientific Apparatus Makers Association, Laboratory Equipment Section, 20 N. Wacker Dr., Chicago 6, Ill.* (L-8)

Electromechanical devices. Bulletin gives specifications for line of synchros, servo motors, and resolvers. *Ketay Mfg. Corp., 555 Broadway, New York 12, N. Y.* (L-9)

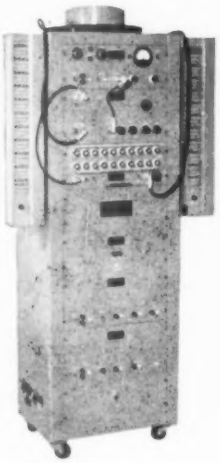
Radiography. "Du Pont Products for Industrial Radiography" provides processing data for films. *E. I. du Pont de Nemours & Co., Photo Products Dept., Wilmington 98, Del.* (L-10)

Research instruments. Brochure describes service for building scientific research instruments. *L. C. Eichner Instruments, 19 Sebago St., Clifton, N. J.* (L-11)

Hydraulic controls. Bulletin 57 covers line of remotely controlled, $^3/_4$-in. 4-way valves. *Pantex Mfg. Corp., Pawtucket, R. I.* (L-12)

Journal index. Index is available listing all issues of Hewlett-Packard Journal from Sept., 1949, through Aug., 1953. *Hewlett-Packard Co., 395 Page Mill Rd., Palo Alto, Calif.* (L-13)

ATOMIC *Instruments* Reliable tools for research

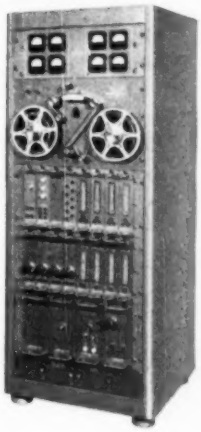


PULSE HEIGHT ANALYZER

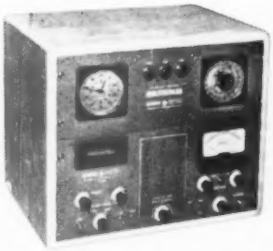
Model 520 Twenty Channel Differential Pulse Height Analyzer — for pulse amplitude distribution studies, divides a spectrum of 60 volts at input of Pulse Sorter into 120 channels, scanning 20 at a time. May be used to study any phenomena where events are expressed in terms of electrical pulses with random amplitudes. Each channel output is fed to a scale of 16 and register for visual indication. All scalers and registers reset by single push button.

Model 510 Single Channel Differential Pulse Height Analyzer for study of amplitude distribution of pulses in the range from zero to 100 volts.

DATA PRINTER



Model 10ABC Analog Voltage Scaler and Rapid Numerical Printer — for reduction of electrical data to printed numerical form. Data in the form of an analog voltage (a direct voltage, the magnitude of which is directly proportional to the represented data value), or in one of several digital forms, may be printed in three-digit Arabic numerals at a rate of 10 to 600 values per second. Figures are printed virtually instantaneously by an all-electronic system on paper tape and no processing is required. When data is in analog form, overall scaling accuracy is ± 0.4%, while digital data is printed with no error.

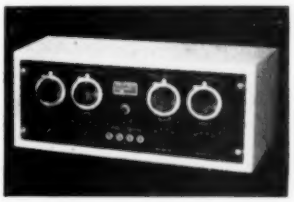


SCALERS

Model 1070A Multiscaler (shown) — a complete scaler for all types of nuclear research; Geiger, Scintillation, or Proportional techniques. Fully automatic operation, with optional choice of five microsecond or one microsecond resolution. Available as decade, scale of 1000 or binary, scale of 4096; also includes built-in pulse amplifier.

Several other models in this Ten-Ten Series are available, each with choice of many features to "customize" scaler for your needs.

COINCIDENCE ANALYZERS



Model 502 Four Channel Coincidence Analyzer — specifically designed for operation with Geiger Counters in cosmic ray or nuclear physics research and for general radioactivity experiments. Any combination of the four channels can be used in coincidence and one channel can be put into anticoincidence. Resolution of 0.25, 0.5, 1 or 2 microseconds selectable for each channel.

Also Model 503C Two Channel Anticoincidence Analyzer — for low level GM tube measurement. Other models available.

LINEAR AMPLIFIERS

Model 204C Linear Amplifier — for use with ionization chambers, scintillation and proportional counters. This model has separate input time constant and rise time settings; gain control by coarse attenuator. Several other models of amplifiers and preamplifiers available.

COUNTING RATE METERS

Model 410 Count Rate Meter — for general laboratory use. Four selectable ranges: 0 - 200 - 2,000 - 20,000 - 200,000 CPM with 2% accuracy. Direct, scintillation and GM probe inputs. High voltage supply, 400 to 2000 V @ 1 ma; 0.05 percent regulation. Includes aural monitor and output for standard 1 ma. pen recorder.

Also Model 409 Laboratory Monitor — a compact bench monitor, with 5% accuracy, for routine laboratory contamination monitoring and many other applications. Various model probes available.

FOR DETAILS REQUEST BULLETIN 10-1

ATOMIC INSTRUMENT COMPANY

84 MASSACHUSETTS AVE. CAMBRIDGE 39, MASS.

Linear Amplifiers, Scalers, High Voltage Supplies, Scintillation Counters, Count Rate Meters, Coincidence and Anticoincidence Instruments, Differential Pulse Height analyzers, Accessories.

SALES REPRESENTATIVES

H. E. RANSFORD CO. — 2601 Grant Bldg., Pittsburgh 19, Pa.
W. A. BROWN & ASSOCIATES — Alexandria, Virginia
Branch Offices — throughout Southeastern U.S.
PACKARD INSTRUMENT CO. — P.O. Box 428, LaGrange, Ill.
KITTLESON COMPANY — Los Angeles 46, Calif.
Branch Offices — San Francisco, Calif. — Albuquerque, N.M.
RON MERRITT COMPANY — Seattle, Wash.
STRAUS-FRANK COMPANY, Eng. Prod. Div. — Houston, Texas
CANADIAN MARCONI CO. — Montreal, P.Q.
Branch Offices—Toronto—Winnipeg—Vancouver—Halifax

Want more information? Use post card insert in this issue.

when QUALITY counts:

when LONG LIFE counts:

when SMALL SIZE counts:

when LOW COST counts:

SPECIFY

RAYTHEON

ALL GLASS, SELF-QUENCHING

COUNTER TUBES

Raytheon All Glass Radiation Counter Tubes come in sizes and prices to meet a broad range of requirements. Raytheon standards of precision manufacture, inspection and testing assure uniformly excellent performance and lasting dependability over a wide temperature range.

RAYTHEON RADIATION COUNTER (GEIGER-MUELLER) TUBES

(All Glass, Self-Quenching)

TYPE	MAX. DIMENSIONS Inches		OPERATING VOLTAGE RANGE Volts dc	PLATEAU LENGTH Volts dc	RELATIVE PLATEAU SLOPE Per 100v	GEIGER THRESHOLD Volts dc max.	BACK-GROUND Unshielded counts/min.	AMBIENT TEMP. RANGE °Cent.	WALL WEIGHT Nominal mg./sq.cm.	EFFICIENCY %	LIFE counts
	Length	Diam.									
CK1890	8¼	1⅛	Thres. +50	>150	3%	1100	60	−40 to +50	35	90	10^8
CK1018	8¼	1⅛	850-950	>150	3%	850	60	−40 to +55	35	90	10^8
CK1019	8¼	1⅛	875-975	>150	3%	880	60	−40 to +55	35	90	10^8
CK1020	6	¾	850-950	>150	3%	850	60	−40 to +55	35	90	10^8
CK1021	5¼	2½	850-950	>150	3%	850	60	−40 to +55	35	90	10^8
CK1023	5	¾	850-950	>150	3%	850	60	−40 to +55	35	90	10^8
CK1026	3	¾	850-950	>150	30%	760	30	−70 to +50	175		10^8
CK1029	5¼	2½	850-950	>150	3%	850	60	−40 to +55	35	90	10^8
CK1032	3	¾	1050-1200	>150	30%	1000	30	−70 to +50	175		10^8
CK1034	2⅛	0.400	700		20%	585		−55 to +70	Hvy		$>10^{10}$
CK1044	1⅛	0-400	700			585		−55 to +70	Hvy		$>10^{10}$

RAYTHEON

Excellence in Electronics

The Raytheon Counter Tubes listed are available from stock through more than 500 Raytheon Tube Distributors.

RAYTHEON MANUFACTURING COMPANY

Receiving Tube Division — Home Office: 55 Chapel St., Newton 58, Mass.

For Application Information Call: Boston, Bigelow 4-7500 • Chicago, NAtional 2-2770 • New York, WHitehall 3-4980 • Los Angeles, Richmond 7-4321

RAYTHEON MAKES ALL THESE:

RELIABLE SUBMINIATURE AND MINIATURE TUBES • SEMICONDUCTOR DIODES AND TRANSISTORS • NUCLEONIC TUBES • MICROWAVE TUBES • RECEIVING AND PICTURE TUBES

Want more information? Use post card insert in this issue.